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A novel ultrasonic underwater propulsion system using a PZT ring transducer

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1. Introduction

Many people today suffer from cardiovascular diseases. To treat cardiovascular diseases, cardiac catheterization is one of the important treatments. However, cardiac catheterization requires manual insertion of the catheter into a blood vessel, which naturally requires a high level of skill on the part of the doctor and still carries the risk of puncturing the blood vessel. Therefore, a novel small actuator using an ultrasonic underwater propulsion system known as swimmers is being actively studied.

Previous swimmer studies have typically used disk-shaped piezoelectric transducers[1)2)3)]. Since this is for medical purposes, wireless control cannot be used for safety and size constraints. If a disk-shaped piezoelectric transducer is used, wires must be led from the outer side of the actuator, but there may be an effect on the treatment effect due to the traction of the wires and the opening on the outer side of the actuator.

Therefore, to reduce the volumes and the resistance, this study was the first attempt to fabricate an actuator using a ring-shaped piezoelectric transducer. The admittance characteristics, and the propulsion of this actuator were measured.

2. Principle of ultrasonic underwater propulsion systems

The principle of ultrasonic underwater propulsion systems using piezoelectric transducers is based on nonlinear acoustics. When the surface of the transducer is in contact with a fluid, different acoustic energy densities are generated between the solid and the fluid due to different acoustic impedances. An acoustic radiation force is generated from the transducer surface to the fluid. The fluid exerts a force on the transducer surface of the same magnitude as the acoustic radiation force but in the opposite direction.

According to the principle of acoustic radiation force, to make the combined force on both sides of the transducer unidirectional propulsion, it is necessary that the two sides of the transducer are in different fluids.

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3. Actuator using a PZT ring-shaped transducer

A PZT ring-shaped piezoelectric transducer used in this study is shown in Fig. 1. The transducer has an outer diameter of 5 mm, an inner diameter of 3.2 mm, and a thickness of 1.4 mm. The piezoelectric material of the ring-shaped transducer is PZT from FUJI CERAMICS CORPORATION's PZT-c213.

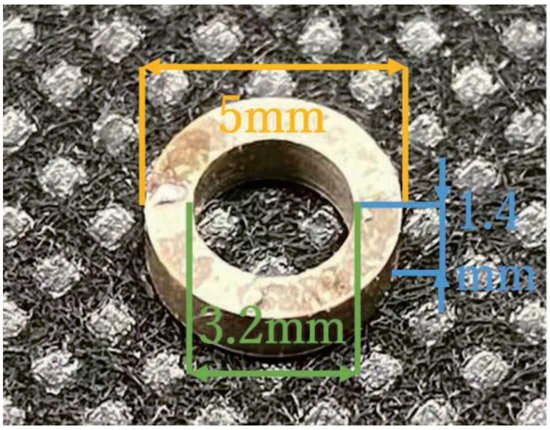
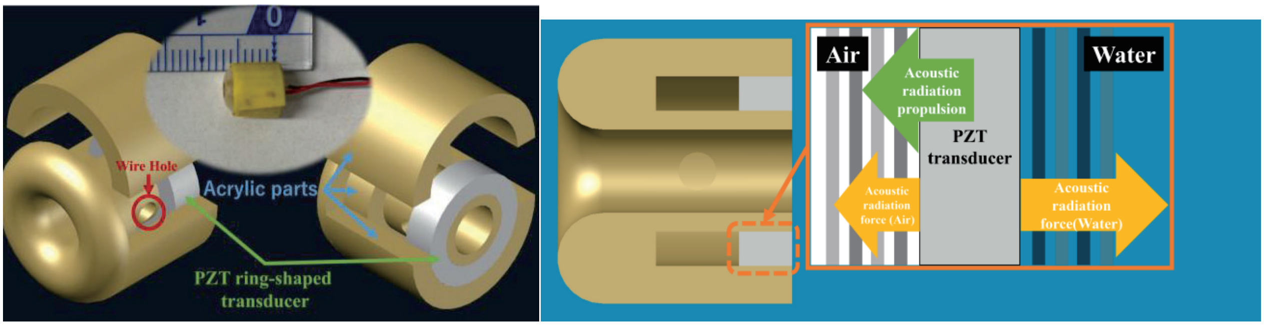


Fig. 1 PZT ring-shaped piezoelectric transducer. (φ5mm(OD) × φ3.2mm(ID); thickness 1.4mm.)

The actuator structure is shown in Fig. 2-(a). The ring-shaped transducer is fixed in the center of a small and a large circular tube and, since the actuator is sealed, one side of the sensor is in contact with air. Wires lead from the middle of the small circular tube. The fixing elements are all 3D printed from acrylic resin.

Due to annular construction of the actuator, as shown in Fig. 2-(b), one side of the ring-shaped transducer is in contact with air and the other side is in contact with water, so that the combined force of the two sides of the ring-shaped transducer become the acoustic radiation propulsion of the water towards the surface of the transducer.

The physical object of the ultrasonic underwater actuator using a PZT ring-shaped transducer is shown in Fig.2-(a). The actuator is about 5mm long and 7mm in diameter.



(a) (b)

Fig. 2 Underwater actuator using a PZT ring-shaped transducer. ((a) Actuator construction; (b) Cross-sectional view of the actuator in water and principle of the ultrasonic underwater propulsion system.)

4. Admittance and propulsion characteristics

The admittance characteristics of the actuator using a PZT ring-shaped transducer were measured, and the results are shown in Fig. 3. From the measurements of the admittance characteristics, the curve of the admittance in water is significantly flatter than that in air. The actuator has a resonance frequency of 1.08 MHz in air and a conductance of 13.09 mS at the resonance frequency as well as a resonance frequency of 1.07MHz in water and a conductance of 5.17 mS at the resonance frequency.

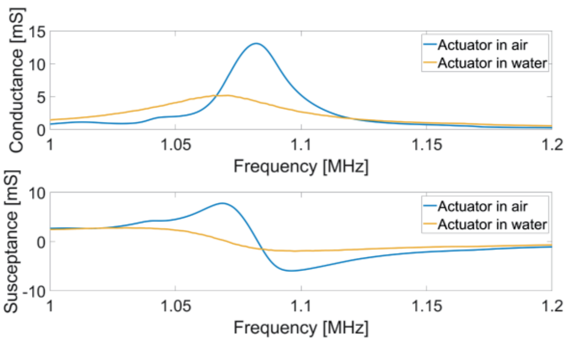


Fig. 3 Admittance characteristics of the actuator.

The propulsion characteristics of the actuator using a PZT ring-shaped transducer driven by a resonance frequency in water (1.07MHz) were measured using a force gauge with an accuracy of 0.1 mN and the results are shown in Fig. 4. When the drive voltage reaches 80$V_{p\text{-}p}$, that is, when the drive power reaches 2.18W, the actuator using a PZT ring-shaped transducer can provide zero speed propulsion of 1mN at the driving frequency.

5. Conclusion

An underwater actuator using a PZT ring-shaped transducer was investigated. The actuator 's admittance and propulsion are measured. The driving frequency of the actuator in water was 1.07 MHz and the conductance at this frequency was 5.17 mS. The actuator could provide 1mN of zero speed propulsion with 2.18W of drive power.

Although the size of the actuator could be smaller, it remains to be explored whether the thrust characteristics can support the operation of the actuator in a blood vessel.

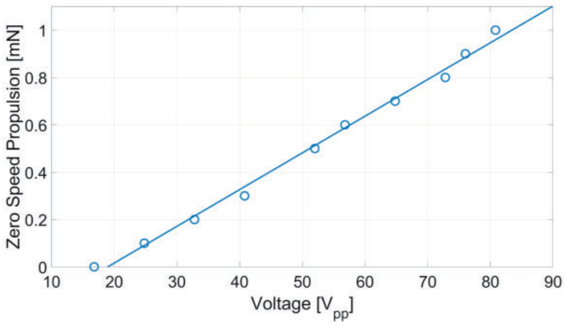


Fig. 4 Propulsion characteristics of the actuator.

Acknowledgment

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