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Evaluation of (Bi,Na,Ba)(Ti,Mn)O_3 and (Sr,Ca)$_2$NaNb_5O_{15} Piezoelectric Ceramics for underwater propulsion systems

液中推進システム用(Bi,Na,Ba)(Ti,Mn)O_3 及び(Sr,Ca)$_2$NaNb_5O_{15}基板の検討

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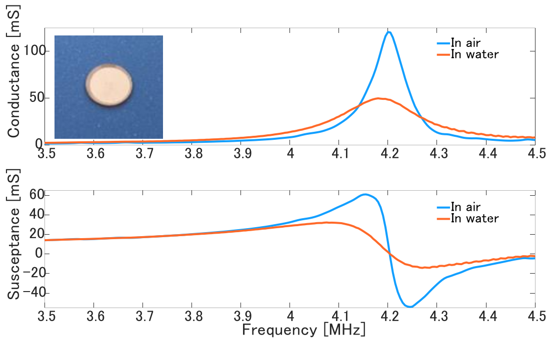
1. Introduction

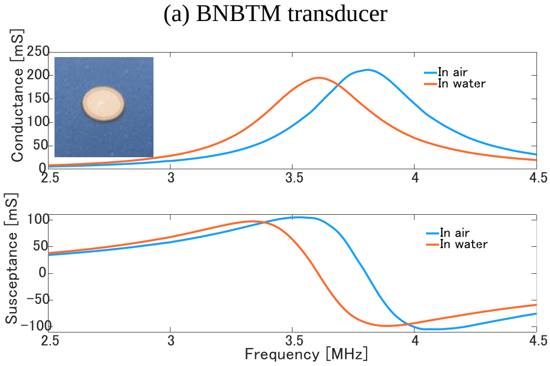
The research of the underwater propulsion system using a thickness-vibration-mode transducer is being carried out actively. Based on the high output energy density and simple structure of the ultrasonic underwater propulsion system, it is easier to miniaturize compared with the traditional electromagnetic motor underwater propulsion system. Thus, the ultrasonic underwater propulsion system is expected to be used in the small pipeline inspection and repair robot. In order to improve the output efficiency of the ultrasonic propulsion system, the ultrasonic transducer is studied. At present, in the absence of a model that can calculate the output efficiency of the ultrasonic underwater propulsion system, comparison experiments using different transducers were attempted. In this research, (Bi,Na,Ba)(Ti,Mn)O_3 (BNBTM) and (Sr,Ca)$_2$NaNb_5O_{15} (SCNN) transducers were investigated not only because of environmental protection but also for their potential in the underwater propulsion system using a transducer.

2.(Bi,Na,Ba)(Ti,Mn)O_3 and (Sr,Ca)$_2$NaNb_5O_{15} transducers

The BNBTM transducer has been used for the first time in an ultrasonic underwater propulsion system. In this research, BNBTM and SCNN transducers were used to compare the propulsion of underwater actuators with different transducers. The molecular structure and nonlinear behavior of BNBTM ceramics are similar to those of Pb(Zr,Ti)O_3 (PZT) ceramics. The equivalent stiffness of BNBTM ceramics and SCNN ceramics decreases and increases with the increase of vibration velocity, respectively. Thus, BNBTM ceramics reflects the soft-spring effect of piezoelectric ceramics, while SCNN ceramics reflects the hard-spring effect of piezoelectric ceramics. In addition, with the increase of vibration velocity, the temperature rise and the quality factor decline of BNBTM ceramics and SCNN ceramics are slower than those of PZT ceramics. In this research, BNBTM (Φ8.5×0.5mm) and SCNN (Φ8.7×0.5mm) transducer are investigated, and the electrode area of both is 38.5 mm^2. Admittance characteristics of BNBTM and SCNN transducers in air and water are shown in Fig. 1. In water, the resonance frequencies of the BNBTM and SCNN transducers are 4.2MHz (conductance: 48.4mS) and 3.61MHz (conductance: 139.8mS), respectively, shown in Fig. 1-(a) and Fig. 1-(b).



(a) BNBTM transducer



(b) SCNN transducer

Fig. 1 Admittance characteristics.

3. Propulsion evaluation of ultrasonic actuator

The principle of an underwater propulsion system using a transducer is based on nonlinear acoustics. when the surface of a transducer is in contact with fluid, different acoustic energy density occur between solid and fluid because of different acoustic impedance. From the surface of the transducer, acoustic radiation force is generated

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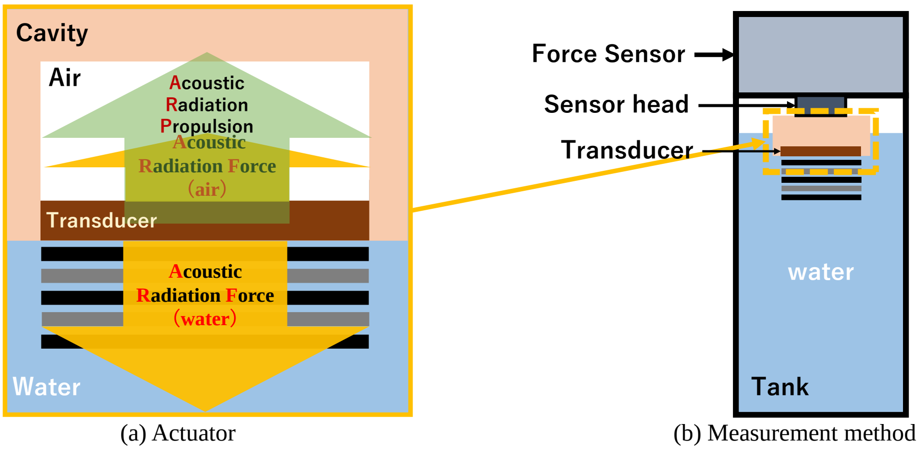

(a) Actuator (b) Measurement method

Fig. 2 Propulsion measurement.

towards the fluid. The force exerted by the fluid to the surface of the transducer is the same as the acoustic radiation force, as the acoustic radiation propulsion which is in the opposite direction. If a transducer is placed in water, according to the principle of acoustic radiation propulsion, both sides of the transducer will receive the same force in the opposite direction. These two forces cancel each other out so that there is no propulsion. As shown in Fig. 2-(a), the upper side of the transducer is in contact with air, and the lower side of the transducer is in contact with water. Different forces are produced in opposite directions on both sides of the transducer. The propulsion generated by the combination of those two different forces.

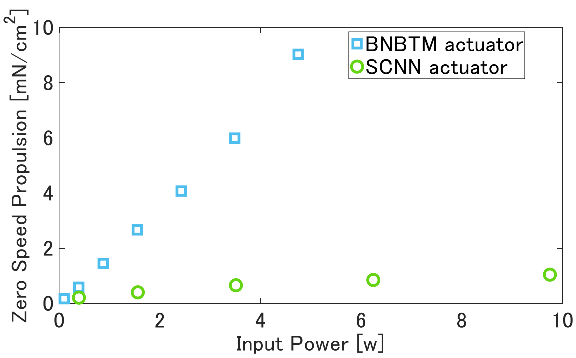

Fig. 3 The result of propulsion measurement.

The underwater actuator as shown in Fig. 2-(a) was built for propulsion measurement. The propulsion of the underwater actuator was measured using a force sensor (Honeywell, FSG005WNPB). The sensor head was connected to the underwater actuator, as shown in Fig. 2-(b). The measurement result of BNBTM and SCNN actuators are shown by the blue square and green circle in Fig. 3, respectively. With the increase of the input power, the propulsion per unit area of BNBTM underwater actuator increases much faster than that of SCNN actuator, indicating that the propulsion provided by BNBTM actuator is greater than that of SCNN actuator under the same input power. The propulsion of the BNBTM and SCNN actuator were 6mN and 0.7mN, when the input power was 3.5W.

4. Conclusion

In this study, BNBTM and SCNN transducers were respectively used in the underwater propulsion system to compare their propulsion. Experimental results show that under 3.5W input power, the propulsion provided by BNBTM and SCNN transducer were 6mN and 0.7mN. Thus, the BNTBTM transducer's lead-free property and excellent performance should be considered as one of the suitable transducers for underwater propulsion systems. In addition, although the performance of SCNN transducer is not ideal, whether the hard-spring effect of SCNN ceramics is not suitable for the ultrasonic underwater propulsion system needs further investigation.

Acknowledgment

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