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A Design and Evaluation of Ultrasonic Motor Using PMN-PT single crystal for ultralow temperature

PMN-PT 単結晶を用いた極低温用超音波モータの試作と評価

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1. Introduction

Many extreme environment conditions are used in the advanced scientific research area. Among them, an ultralow temperature condition which is near the liquid helium temperaure is an important condition in some chemical and some biological analysis technology.[1)] Additonally, there is a demand for actuators which has high speed rotation at ultralow temperature.

Previously, we have fabricated the ultrasonic motor which can be rotated at 65 rpm in 4.5 K liquid herium gas.[2, 3)] However, the motor has a lmitation of its output power because the piezoelectricity of a PZT used at the transducer decreases at ultralow temperature.

In this report, an ultrasonic motor for ultralow temperature which has higher speed rotation than previous our motor is fabricated and evaluated. The motor has a bolt-clamped Langevin-type transducer using PMN-PT single crystal. PMN-PT single crystal shows smaller decreasing of the piezoelectricity than PZT.[4)]

2. Structure of the Motor

The structure of the motor is shown in **Fig. 1**. The motor consists of a transducer, a slit plate, a casing, a bearing, a spring, a few copper rings, and a rotor. The rotor has a contact with the tip of the transducer. The contact pressure is generated by the spring and adjusted by the number of the copper rings. The rotor is rotated by the traveling wave on the tip of the transducer and the friction force between the rotor and the tip of the transducer. In an ultralow temperature condition, the rotation speed is measured by using the optical fiber sensor and slit plate. The maximum diameter and the height of the motor are 22 mm and 30.5 mm.

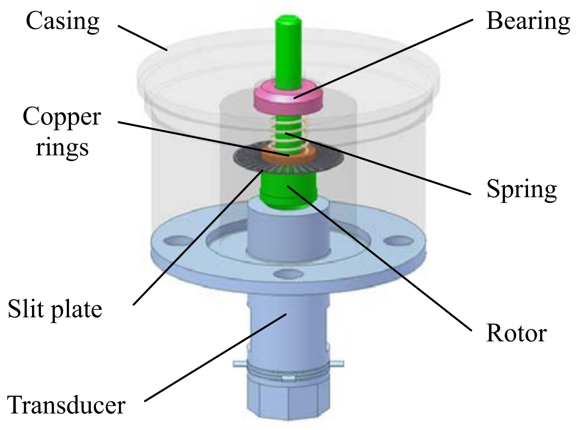

Fig. 1 Structure of the ultrasonic motor

Figure 2 shows the structure of the transducer. The transducer consists of a body, two ring electrodes, four quartered electrodes, a nut, two PMN-PT single crystal rings, and a bolt. The PMN-PT rings are 0.2 mm thick and are polarized in the thickness direction. The transducer generates the flexural vibration mode in each perpendicular direction when the quartered electrodes is applied a sinusoidal wave voltage that has a phase difference at 90 deg. The maximum diameter and length of the transducer are 20 mm and 16 mm.

3. Evaluation of the transducer

We have measured the vibration velocity of the transducer at room temperature. **Figure 3** shows the relationship between the driving frequency and the vibration velocity at the tip of the transducer at 300 K. The maximum vibration velocity was 448 mm/s when the clamping torque, the applied voltage and the frequency were 1.0 Nm, 150 V_{p-p} and 76.2 kHz respectively. The clamping torque was decided by evaluation of the admittance of the transducer.[5)]

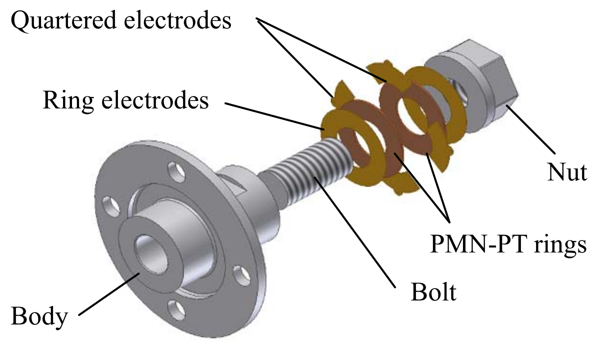

Fig. 2 Structure of the bolt-clamped Langevin-type transducer

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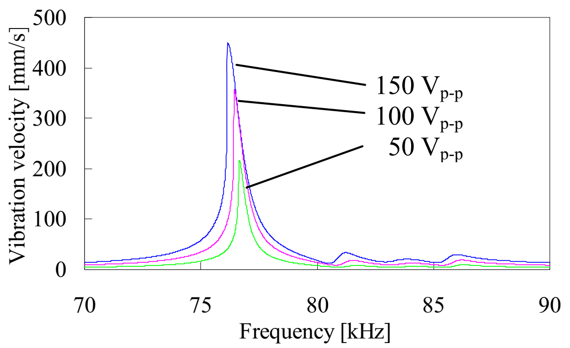

Fig. 3 Relationship of the driving frequency and the vibration velocity at 300K

4. Evaluation of the Ultrasonic Motor at Ultralow Temperature

The ultrasonic motor was driven at ultralow temperature. The motor was cooled by cryogenic helium gas on the liquid helium in a cryogenic actuator evaluation system.[3] The resonance frequency increased with decreasing the temperature of the transducer. Therefore, the driving frequency is adjusted at each temperature.

The relationship between the driving temperature and the rotation speed is shown in **Fig. 4**. The applied voltage and the clamping torque of the transducer were 150 V_{p-p} and 1.0 Nm. Young's module increases at ultralow temperature. Then, the spring constant increase and the contact pressure change. Therefore, we have evaluated the rotation speed at ultralow temperature when the contact pressure is changed. The contact pressure was adjusted by the number of the copper rings that thickness is 0.1 mm. The lowest rotatable temperature was 4.4 K and the maximum rotation speed was 144 rpm at its temperature. The contact pressure, driving frequency and electrical current were 0.139 N, 79.6 kHz and 31.2 mA, respectively.

Figure 5 shows a comparison of the rotation speed of the motor using PMN-PT single crystal and using PZT ceramics. When the motor using the PZT was driven, the contact pressure, driving frequency, applied voltage and electric current were 0.126 Nm, 82.45 kHz, 150 V_{p-p} and 20.6 mA, respectively.

5. Conclusion

In this paper, the ultrasonic motor for ultralow temperature environment is fabricated and evaluated. The motor has a transducer using PMN-PT single crystal in order to inhibit an influence of a decreasing a piezoelectricity.

The motor is driven in ultralow temperature helium gas. The rotation speed was 144 rpm at 4.4 K. This rotation speed is 2 times higher that of our previous motors. This result shows that a transducer

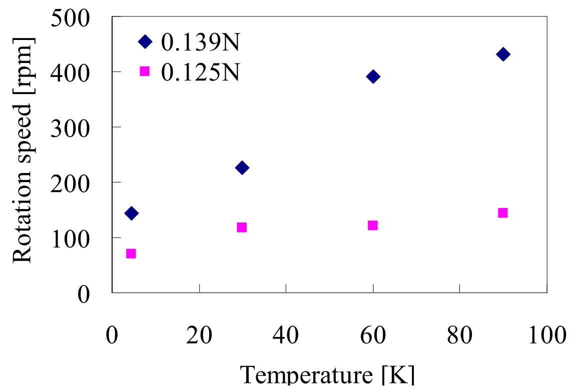

Fig. 4 Relationship of the driving temperature and the rotation speed at each contact pressure

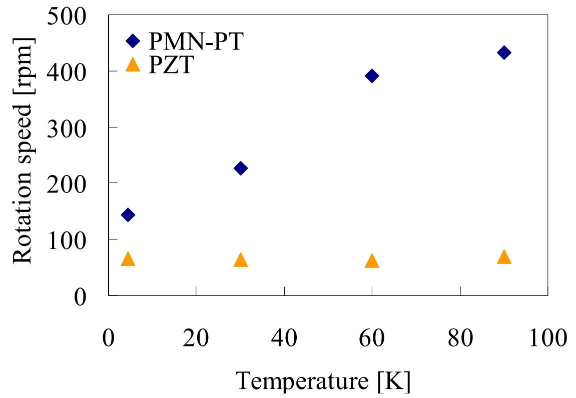

Fig. 5 Comparison between the rotation speed of the motor using PMN-PT and using PZT

using PMN-PT single crystal would be effective at ultralow temperature.

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