1P4-7

Evaluation of Transducer for Cryogenic Actuators by Equivalent Circuit Model

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1. Introduction

Recently, the use of cryogenic temperatures has been increasing in the scientific and industrial fields. The cryogenic environment is in the range of 0.3K~20K, which enables high precision measurements such as NMR due to suppression of thermal noise and reduction of recoil velocity[1)]. Recently, liquid hydrogen has been getting a lot of attention and is essential for the realization of a decarbonized society[2)]. The boiling temperature of liquid hydrogen is 20K, and valves are needed to control such cryogenic fluid. For these reasons, cryogenic micro actuators are needed.

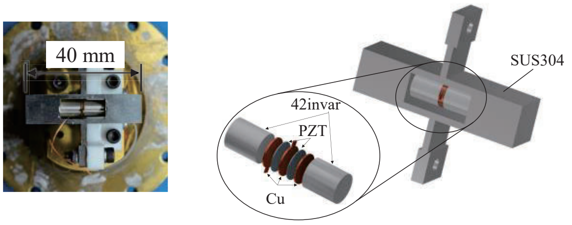
In general, electromagnetic actuators have the advantage of high torque. However, electromagnetic actuators have the disadvantage of generating magnetic noise and giving up heat to the low-temperature fluid. On the other hand, piezoelectric actuators have the advantage of being easily miniaturized and having a large volumetric output ratio. However, one disadvantage is that piezoelectric performance degrades as temperature decreases. To solve this problem, application of a preload to the piezoelectric element was studied[3)]. In a previous study, a mechanism of applying a preload to a piezoelectric element using the difference in thermal contraction between two metals with different thermal expansion coefficients was proposed[4)].

In this study, thermal of parts for the transducer has been changed and the fabricated transducer has been evaluated.

2. Structure and Evaluation of Transducer

The fabricated transducer is shown in **Fig. 1**. The transducer in previous study had internal parts made of titanium[4)]. As shown in Fig. 1, internal parts were changed to 42 invar. The 42 invar, nickel alloy, has a lower thermal expansion coefficient than titanium. Therefore, the difference in thermal shrinkage between the transducer body made of SUS304 and the internal parts is large. A larger preload is expected to be applied to the piezoelectric elements.

To evaluate the performance of the fabricated transducer, admittance of the transducer was first measured when the temperatures were 295K, 20K, and 4.5K. A cryostat was used to achieve a cryogenic environment. The admittance loops drawn from the measured values are shown in **Fig. 2**. Figure 2 shows that the admittance loops at low temperatures is larger than those at room temperature. Next, the vibration velocity of the transducer was measured at the same conditions by using a laser Doppler vibrometer. The vibration velocities are shown in **Fig. 3**. Figure 3 shows that the vibration velocity is also higher at low temperatures. Finally, **Fig. 4** shows the change in vibration velocity when the driving voltage is varied for the transducers using 42 invar and those using titanium at 4.5 K. **Figure 5** shows that the transducer in this study have larger vibration velocities than those in previous study. This result indicates that the material change improves the vibration performance.



(a) Photo of transducer (b) Schematic transducer

Fig. 1 Proposed and fabricated transducer which consists of parts made of 42 invar

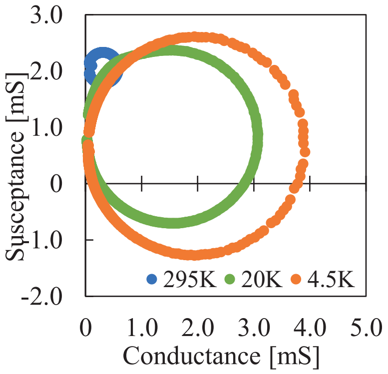


Fig. 2 Admittance loop when the temperature was changed

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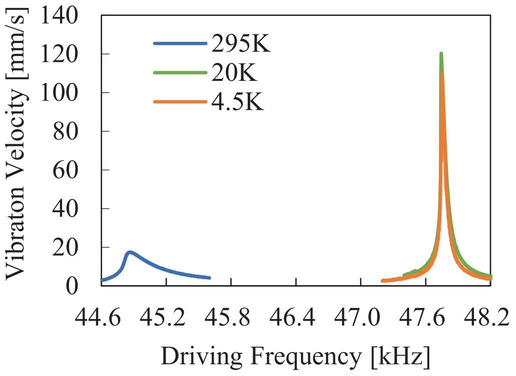

Fig. 3 Relationship between vibration velocity and driving frequency when the driving voltage was 20V as peak to peak value

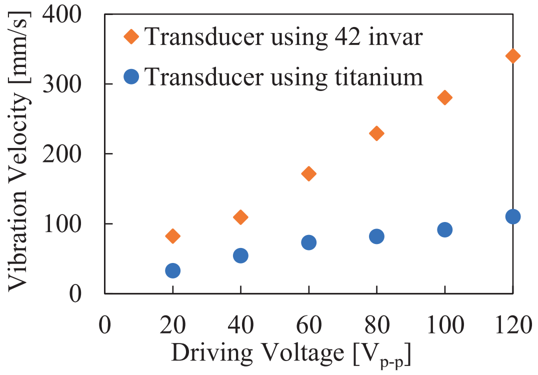

Fig. 4 Relationship between vibration velocity and driving voltage when the temperature 4.5K

3. Evaluation using equivalent circuit

To calculate the force factor of the transducer, the equivalent circuit shown in **Fig. 5** is used. In Figure 5, R_m, L_m, C_m, and C_d are an equivalent resistance, an equivalent inductance, an equivalent capacitance, and a braking capacity, respectively. These can be estimated from the admittance loops in Fig. 2. The dynamic current, I_m, was calculated using the MATLAB Simulink Frequency Response Estimator. The force factor, A, can be obtained using dynamic current, I_m, and the vibration velocity, v.

The values used to calculate the force factors are shown in **Table I**. Table I shows that the force factor decreases with decreasing temperature.

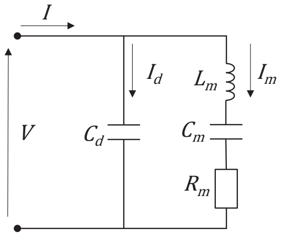

Fig. 5 Equivalent circuit of the transducer[5)]

Table I Parameters and estimated values when the temperature was changed

	295K	20K	4.5K
R_m[Ω]	1.69×10^{3}	3.25×10^{2}	2.55×10^{2}
L_m[H]	2.02	3.92	7.25
C_m[F]	6.45×10^{-12}	2.83×10^{-12}	1.53×10^{-12}
C_d[F]	6.42×10^{-9}	2.54×10^{-9}	2.15×10^{-9}
Q_m	331.7	3619	8531
v [mm/s]	17.41	120.4	109.6
I_m[mA]	0.430	0.208	0.113
A [N/V]	2.47×10^{-2}	1.73×10^{-3}	1.03×10^{-3}

4. Conclusion

In this study, the aim is to improve the performance of previous transducer by changing materials, and to calculate the force factor by using an equivalent circuit. By changing the internal parts of the transducer from titanium to 42 invar, the vibration performance has been improved in the cryogenic environment. Experimental results show that the preload mechanism has been improved. The force factor of the transducer has been estimated by using the equivalent circuit and measured values. The results show that the force factor depends on the temperature.

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