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Evaluation of a vibrator for a cryogenic ultrasonic motor using titanium
チタンを用いた極低温環境用超音波モータ用振動子の評価

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1. Introduction

The solid state nuclear magnetic resonance spectroscopy (solid state NMR) can realize observations of the molecular structure by rotating solid samples in a high intense magnetic field.[1,2)]Observation of molecular structure and superconducting phenomenon is realized by means of solid state NMR in a cryogenic environment. For the solid state NMR in a cryogenic environment, a motor rotating at high speed in a cryogenic environment is required.

Ultrasonic moters which can be driven in a cryogenic environment using stainless steel have been studied.[3-6)] However, the thermal expansion coefficient of SUS304 is twice as high as that of PZT used as a piezoelectric material. Therefore, large thermal stress was applied to PZT in a cryogenic environment.

In this study, titanium parts have been used for the cryogenic ultrasonic motor instead of stainless steel parts. Titanium has toughness in a cryogenic environment. Moreover, the thermal expansion coefficient of titanium is close to that of PZT. We aim to realize an ultrasonic motor which has small thermal stress in a cryogenic environment.

2. Structure of the transducer

Figure 1 shows a structure of a prototype transducer. The transducer is made of titanium, PZT and copper. PZT is polarized in the thickness direction and silver electrodes are deposited on both sides of the PZT elements. One side silver electrode is divided into four.[6)]

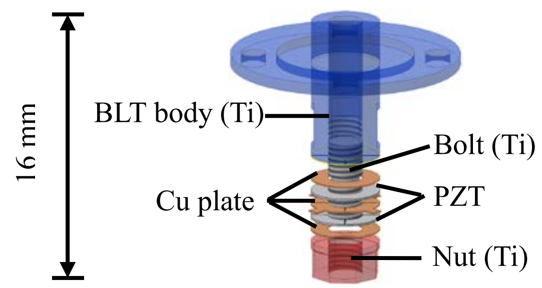

Fig. 1 Structure of the transducer

3. Simulation about thermal stress on vibrator

The value of piezoelectric constant increases by applying a pressure to PZT. On the other hand, if pressure is too large, the value of piezoelectric constant decreases. Thus, it is necessary to add the optimum pressure on PZT. The optimum pressure was evaluated by the admittance and the clamping torque.

The pressure applied to PZT is changed by thermal stress in a cryogenic environment. Therefore, it is necessary to estimate the optimum clamping torque in a cryogenic environment.

First, we simulated thermal stress applied to PZT by finite element method (FEM). Figure 2 shows a cross sectional view of the titamium transducer changing temperatures from 300 K to 4.5 K. Thermal stress applied to PZT is 0.9 MPa at 4.5 K as shown in Fig. 2. Figure 3 shows the relationship between the temperature and the thermal stress obtained by FEM. Comparing thermal stress of the titanium transducer and that of the SUS304 transducer,[6)] the titanium transducer is less than the SUS304 transducer. Thermal stress of the titanium transducer is maximum of 17.6 MPa and the SUS304 transducer is maximum of 65.6 MPa. This is because the thermal expansion coefficient of titanium is close to that of PZT than that of SUS304. Furthermore, based on values obtained by the simulation, we estimated the optimum clamping torque considering thermal stress to PZT at each temperature.

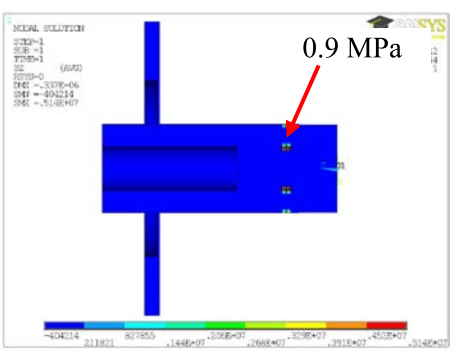

Fig. 2 Cross sectional view of simulation result about thermal stress of the titanium transducer when the temperature is 4.5 K

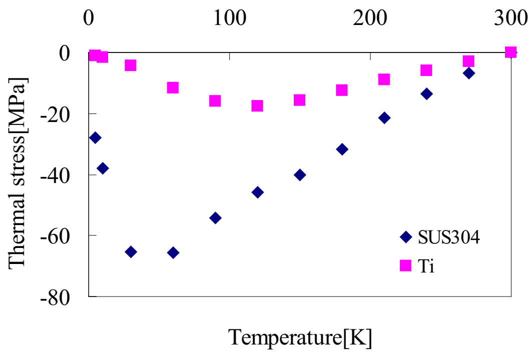

Fig. 3 Relationship between the temperature and thermal stress simulated by FEM[7,8]

4. Evaluation of the transducer at the cryogenic emvironment

Next, we measured admittances when varying the clamping torque. Figure 4 shows The relationship between the clamping torque and the admittance at each temperature. The optimum clamping torque was 0.6 Nm at 300 K. The optimum clamping torque in a cryogenic environment obtained by the experiment was 0.5 Nm.

Figure 5 shows comparison of the calculated value with the experimental value of the optimum clamping torque. The difference between experimental and calculated values were 0.1 Nm at best. This means that adjustment of the clamping torque is not required in a cryogenic environment.

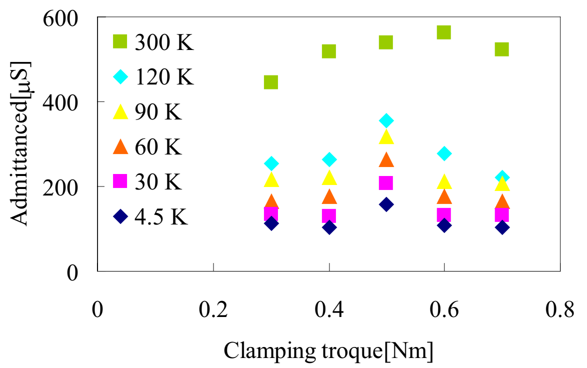

Fig. 4 Relationship between the clamping torque and the admittance

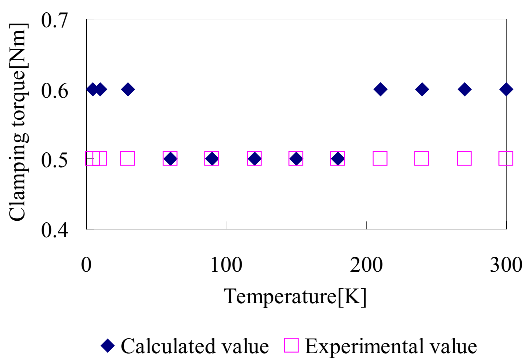

Fig. 5 Comparison of caluculated value with experimental value of the optimum clamping torque

5. Conclusion

We have fabricated the transducer using titanium. We have evaluated the optimum clamping torque in a cryogenic environment. The optimum clamping torque is evaluated by the admittance of the titamium transducer.

We have simulated thermal stress applied to PZT by FEM. Comparing thermal stress of the titanium transducer and that of the SUS304 transducer, the titanium transducer had smaller thermal stress than the SUS304 transducer. This is because the thermal expansion coefficient of titanium is close to that of PZT than that of SUS304.

The optimum clamping torque in a cryogenic environment obtained by experiment was 0.5 Nm. We have compared the experimental value with the calculated value of the optimum clamping torque. The difference between experimental and calculated values were 0.1 Nm at best. This means that adjustment of the clamping torque is not required in a cryogenic environment. Therefore, the titanium transducer used PZT is suitable for a cryogenic environment than the SUS304 transducer.

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