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Frequency Response Characteristics of Piezoelectric Complex Bar Resonator using Longitudinal-torsional Vibration Converter

縦ねじり変換器を用いた圧電型複合振動子の周波数応答特性

Subaru Kudo (Ishinomaki Senshu Univ.)
工藤 すばる（石巻専修大 理工）

1. Introduction

In the field of high-power ultrasonics, it has been studied that a small and large torque ultrasonic rotating device can be realized using a longitudinal-torsional vibration converter with diagonal slits [1]. The authors have already reported that the complex bar resonator capable of simultaneously driving the longitudinal mode and the torsional mode can be realized by inserting a longitudinal-torsional vibration converter into a part of the bar resonator[2)-4)]. In this study, in order to clarify the relationship between the electrical characteristics of the complex bar resonator and the vibration displacement, the frequency response characteristics of the bar resonator is analyzed using the finite element method.

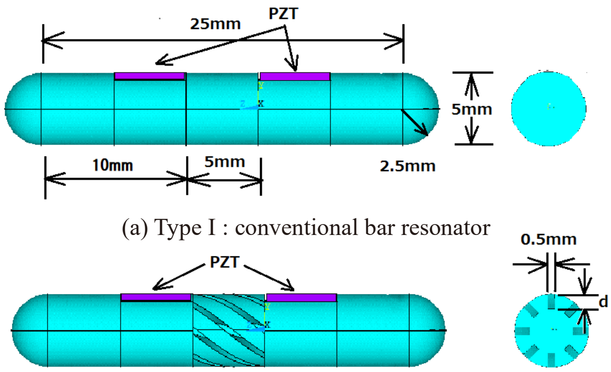
2. Structure of complex bar resonator

Figures 1(a) and 1(b) show the finite element model of the piezoelectric bar resonator. The conventional bar resonator is shown in Fig.1(a), and the complex bar resonator using a longitudinal-torsional vibration converter with consists of 8 diagonal slits(d=1.5mm) is shown in Fig.1(b). Piezoelectric ceramic plates (Nepec-6) were attached to the bar resonator to drive these resonators and to investigate the electrical characteristics. The frequency response characteristics, resonance frequencies, vibration modes and displacement distributions of the bar resonators are calculated by the finite element program of ANSYS ver.16 (Cybernet Co.,Ltd.). The characteristics of piezoelectric complex bar resonator are considered from the viewpoint of electrical characteristics and vibration mode. The material constants of the resonator are shown in **Table I**.

3. Results of finite element analysis

3.1 Calculated characteristics of frequency response

Figure 2 shows the calculated results of frequency response characteristics on the conventional bar resonator in Fig.1(a). The vibration mode on resonance frequency of 87.47kHz in Fig.2 is shown in Fig.3. It was confirmed that this vibration mode was a longitudinal mode. In the structure in Fig.1(a), a torsional vibration mode was obtained at 54.4kHz by eigenvalue analysis, but it was not



(a) Type I : conventional bar resonator

(b) Type II : complex bar resonator

Fig.1. FEM models of piezoelectric bar resonators.

Table I. Material constants of resonator.

Young's modulus E (N/m^2)	1.99×10^{11}
Poisson's ratio σ	0.34
Density ρ (kg/m^3)	7900

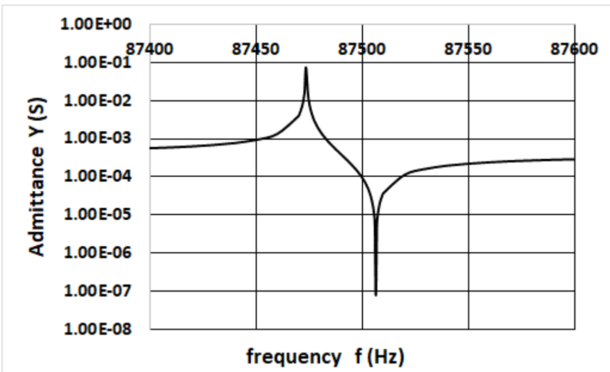
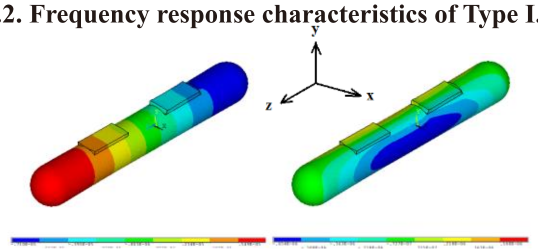


Fig.2. Frequency response characteristics of Type I.



(a) z direction **(b) x direction**

Fig.3. Vibration displacements of conventional bar resonator (f=87.47kHz).

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kudou@isenshu-u.ac.jp

obtained in frequency response analysis. On the other hand, Fig.4 shows the calculated results of frequency response characteristics on the complex bar resonator in Fig.1(b). The vibration mode on resonance frequency of 70.59kHz is shown in Fig.5. It was confirmed that this vibration mode was a complex mode combining a torsional mode and a longitudinal mode. In the structure in Fig.1(b), a complex vibration mode was obtained at 33.52kHz by eigenvalue analysis, but it was not obtained in frequency response analysis. Table II summarizes the electrical characteristics. It became clear that the capacitance ratio increases with complex vibration.

Table II. Electrical characteristics.

Type	I	II
Resonance frequency(kHz)	87.473	70.592
Anti-resonance frequency(kHz)	87.506	70.606
Capacitance ratio γ	1325	2451

3.2 Displacement analysis of vibration modes

Figure 6 shows the relative displacement distribution of the conventional bar resonator in Fig.3. The relative displacements are expressed as U_z/U_0 and U_x/U_0, where U_z is the vibration displacement in the z direction at the center axis, U_x is the displacement in the x direction at the side face of the resonator and U_0 is the maximum displacement of the resonator. Since U_x/U_0=0, it can be seen that this mode is a longitudinal vibration mode. **Figure 7** shows the relative displacement distribution of the complex bar resonator in Fig.5. Comparing the displacement of U_z/U_0 with that of U_x/U_0, it can be seen that the longitudinal vibration is the main mode because the displacement of the center axis on the resonator is larger than the displacement of the side face. The complex vibration ratio between the longitudinal mode and the torsional mode is calculated as U_x/U_zmax=0.69. It is considered that the capacitance ratio of complex bar resonator in Table II increased due to this complex vibration.

4. Conclusion

The frequency response characteristics of complex bar resonator using a longitudinal-torsional converter were examined by the finite element method. It was clarified that the relationship between the electrical characteristics and the complex vibration ratio. This work was partially supported by a grant from Research Center for Creative Partnerships, Ishinomaki Senshu University.

References

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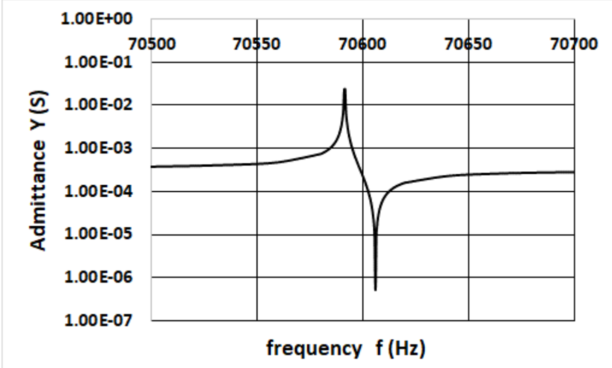

Fig.4. Frequency response characteristics of Type II.

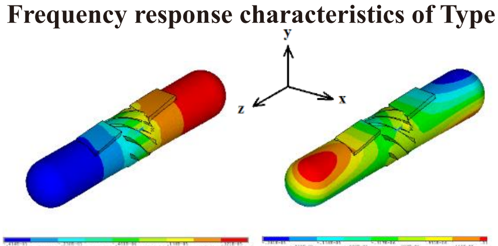

Fig.5. Vibration displacements of complex bar resonator (f=70.59kHz).

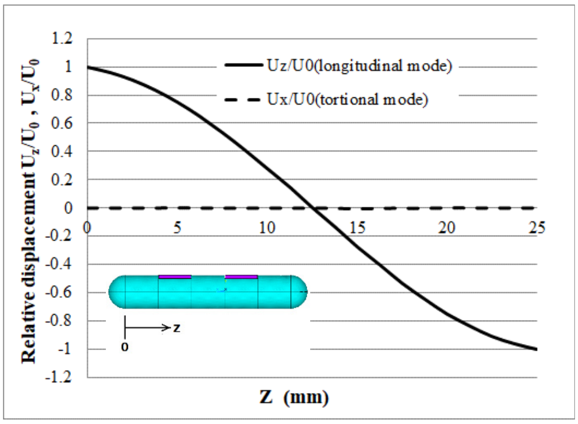

Fig.6. Relative displacement distribution of conventional bar resonator in Fig.3.

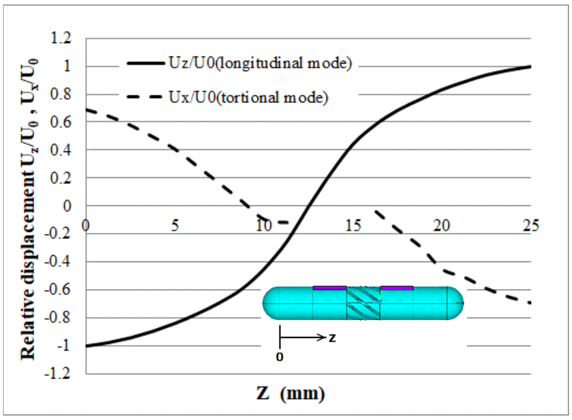

Fig.7. Relative displacement distribution of complex bar resonator in Fig.5.