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# Finite element analysis of the complex bar resonator with longitudinal-torsional vibration converter

縦ねじり変換器を有する複合型細棒振動子の有限要素法解析

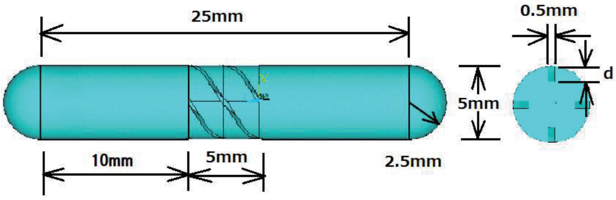
Subaru Kudo†, Yoshifumi Sasaki, and Sumio Sugawara (Ishinomaki Senshu Univ.)
工藤 すばる†, 佐々木 慶文, 菅原 澄夫（石巻専修大 理工）

## 1. Introduction

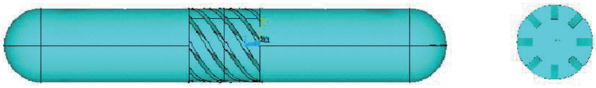
In the field of high-power ultrasonics, it has been reported that a small and large torque ultrasonic rotating device can be realized using a longitudinal-torsional vibration converter with diagonal slits [1]. The authors have already reported that the complex bar resonator capable of simultaneously driving the longitudinal mode and the torsional mode can be realized by inserting a longitudinal-torsional vibration converter into a part of the resonator [2], [3]. In this study, the characteristics between the slit angle of the converter and the complex vibration displacement ratio are calculated by the finite element method. First, the relationship between the resonance frequency of the resonator and its complex vibration mode was analyzed with respect to the slit depth of the converter. Next, the displacement distribution of the complex vibration mode of the resonator was analyzed and the complex vibration displacement ratio was examined. Furthermore, the relationship between the slit angle and the displacement ratio was clarified.

## 2. Structure of complex bar resonator

**Figures 1(a) and 1(b)** show the finite element model of the complex bar resonator. The longitudinal-torsional vibration converter consists of cylinder with 4 diagonal slits in Fig.1(a) or with 8 diagonal slits in Fig.1(b). The resonance frequencies, vibration modes and displacement distributions of the complex bar resonator are calculated by the finite element program of ANSYS ver.16 (Cybernet Co.,Ltd.). The relationships between the characteristics of the resonator and the diagonal slit angle of θ are considered from the viewpoint of complex vibration. The material constants of the resonator are shown in **Table I**.



(a) Converter with 4 slits



(b) Converter with 8 slits

**Fig.1. FEM model of complex bar resonator(θ=45°).**

**Table I. Material constants of resonator.**

| | |
|---|---|
| Young's modulus E (N/m$^2$) | $1.99\times10^{11}$ |
| Poisson's ratio σ | 0.34 |
| Density ρ (kg/m$^3$) | 7900 |

## 3. Results of finite element analysis

### 3.1 Calculated results of resonance frequencies

**Figure 2** shows the calculated results of resonance frequencies on the complex bar resonator composed of the converter with 8 slits in Fig.1(b). When the slit depth of the converter increased, the resonance frequencies in the torsional and the longitudinal modes decreased gradually. Then, the resonance frequencies in the longitudinal mode tended to decrease as the smaller the slit angle. The complex vibrations of the longitudinal mode and the torsional mode were confirmed except the case for d=0mm.

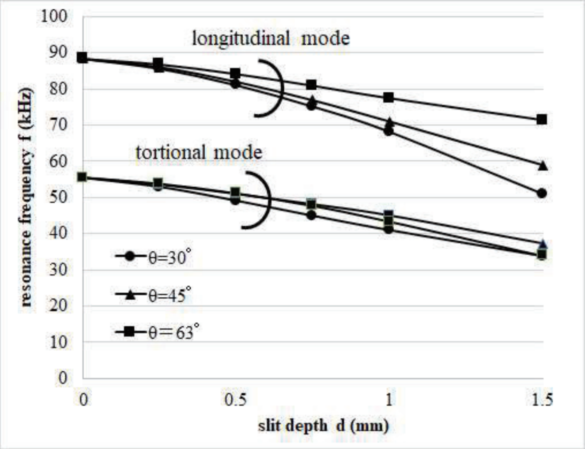


**Fig.2. Calculated results of resonance frequencies (converter with 8 slits).**

### 3.2 Displacement analysis of complex vibration modes

**Figures 3(a) and 3(b)** show the vibration displacement of the complex bar resonator with a frequency of 59kHz at d=1.5mm and θ=45° in Fig.2.

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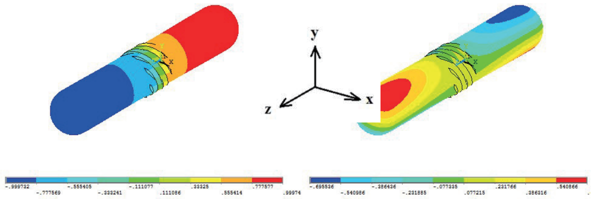
kudou@isenshu-u.ac.jp

It was confirmed that this vibration mode was a complex mode combining a torsional mode and a longitudinal mode. **Figure 4** shows the relative displacement distribution of the complex resonator in Fig.3. The relative displacements are expressed as $U_x/U_0$ and $U_z/U_0$, where $U_x$ is the vibration displacement in the x direction at the side face of the resonator, $U_z$ is the displacement in the z direction at the center axis and $U_0$ is the maximum displacement of the resonator. Comparing the displacement of $U_x/U_0$ with that of $U_z/U_0$, 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.



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

**Fig.3. Vibration displacements of complex bar resonator (slit number 8,d=1.5mm,θ=45°,f=59kHz).**

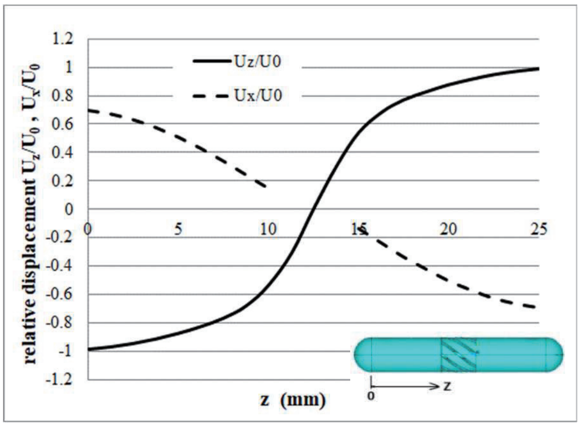


**Fig.4. Relative displacement distribution of complex bar resonator in Fig.3.**

## 3.3 Analysis of complex vibration displacement ratio

**Figure 5** shows the examined results of the complex vibration displacement ratio in the case that d=1.5mm and θ=45°. The complex vibration ratios between the longitudinal mode and the torsional mode are expressed as $U_x/U_{zmax}$ and $U_z/U_{xmax}$ . The complex vibration ratio of $U_x/U_{zmax}$ is mainly a longitudinal mode superimposed by a torsional mode. The ratio of $U_z/U_{xmax}$ is mainly a torsional mode superimposed by a longitudinal mode. It became clear that the complex vibration ratio increases as the slit depth increases. At the same slit depth, the complex vibration ratio becomes larger when the main vibration is longitudinal mode. On the other hand, **Fig.6** shows a summary of the complex vibration ratio $U_x/U_{zmax}$ for the slit angle of θ. The displacement ratio $U_x/U_{zmax}$ of torsional vibration to longitudinal vibration varies greatly depending on the silt angle, and becomes maximum when the angle is between 45 and 60 degrees.

## 4. Conclusion

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

### References

1. J.Tsujino,et al:Technical report of IEICE,US95-69 (1995-12) 9 [in Japanese].
2. S.Kudo: Proc. Autumn Meet. Acoust. Soc. Jpn. ,No.3P18, pp.119-120 (2018) [in Japanese].
3. S.Kudo,Y.Sasaki and S.Sugawara : Proc. Symp. Ultra. Elect., Vol.39, No.2P3-4(2018).

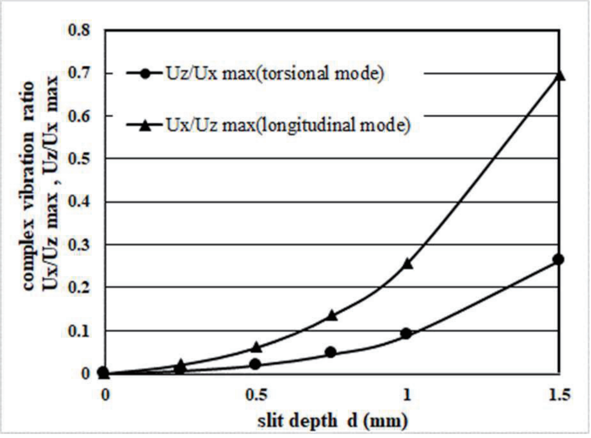


**Fig.5. Characteristics of complex vibration ratio I (slit number 8, θ=45°).**

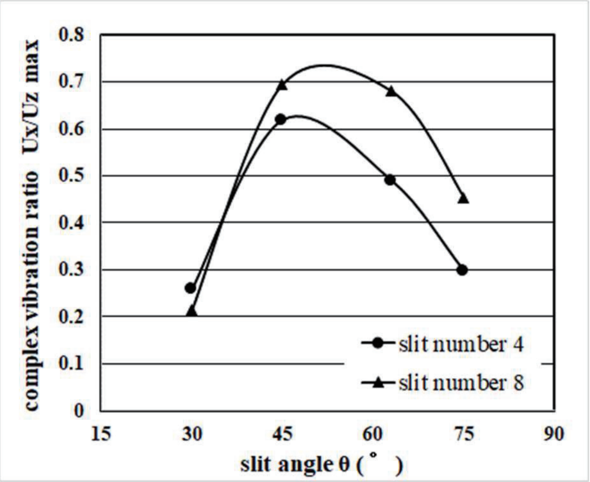


**Fig.6. Characteristics of complex vibration ratio II (d=1.5mm).**