# 2P1-7

# Fundamental Consideration on Numerical Analysis of the Vibrating Propagation on the Acoustic Waveguide for Coiled Stator Ultrasound Motor

コイル状ステータ超音波モータのための音響導波路上の振動伝搬解析に関する基礎検討

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## 1. Introduction

In our laboratory, we have been developing a coiled stator ultrasound motor (CS-USM) for medical application like Intra Vascular Ultra Sonograph (IVUS)[1-2]. So far, the CS-USM of various structures have been reported, for example, using a piezoelectric ceramic transduser or a hydrothermally synthesized PZT polycrystalline film transducer, single transducer type CS-USM, dual transducer type CS-USM[3]. However, the wave propagation on an acoustic waveguide has not been investigated sufficiently in our conventional study. Analysis of wave propagation is very important to fabricate smaller and more efficient CS-USM.

In this paper, we report the analysis of the sound velocity of the wave propagation on the straight flat plate acoustic waveguide by three dimensional finite element method (FEM) simulation.

## 2. Outline of the Coiled Stator Ultrasound Motor

The structure of CS-USM consists of three parts of a piezoelectric transducer, an coiled acoustic waveguide stator , and a rotor. The CS-USM is the traveling wave type ultrasonic motor where the elliptical particle movement on the surface of the coiled acoustic waveguide which rotate the rotor. The piezoelectric transducer is mounted near an end of the acoustic waveguide, and the rotor is placed in the hollow of the coiled stator. The elastic guided wave is generated by the piezoelectric transducer as the driving source and propagates along the acoustic waveguide. The particles on the surface of acoustic waveguide are elliptically moved by the elastic guided wave, and the rotor is rotated by elliptical motion of the particles on the surface of the coiled acoustic waveguide stator. Fig.1 shows a structural diagram of CS-USM.

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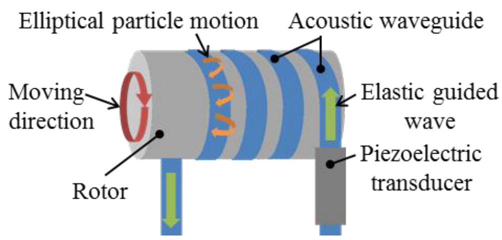


Fig. 1 Structural diagram of the CS-USM

## 3 Analysis Method

### 3.1 Finite Element Method for Analysis

In this study, we use three-dimensional FEM analysis using ANSYS®. Figure 2 shows the simulation model. In this paper, we analyzed the propagation of elastic guided wave on the straight Ti acoustic waveguide for the coiled stator with the piezoelectric transducer which is mounted near an end of the straight acoustic waveguide. This acoustic waveguide is not coiled for basic consideration.

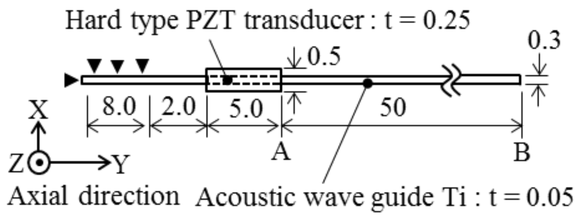


Fig.2 Three-dimensional simulation model of the straight Ti acoustic waveguide with the piezoelectric transducer which is mounted near an end of the acoustic waveguide

Hard type PZT transducer (Fuji Ceramics CO., LTD.) with length of 5 mm, width of 1 mm, and thickness of 0.25 mm is used in analysis. The acoustic waveguide has width of 0.3 mm, thickness of 50 μm and length of 50 mm from the right end of the piezoelectric transducer (between positions A and B in Fig.2). The acoustic waveguide was clamped by setting the displacement in the range of 8 mm from left end and the left end of the acoustic waveguide to zero (fully constrained state). The material properties of titanium (Density: 4540 $kg/m^3$,Young's modulus: 116 GPa, Poisson's ratio: 0.32) were used for the acoustic waveguide. Analysis was performed at frequency every 10 kHz between 100 kHz and 500 kHz. The applied voltage was set at 20 $V_{p\text{-}p}$.

### 3.2 Propagation Velocity of Acoustic Waveguide

In this analysis, propagation velocities of longitudinal wave (UY), vertical shear wave (UZ) and horizontal shear wave (UX) including in the elastic guided wave were calculated from the wavelength of each wave displacement (UX, UY, UZ) by using frequency response analysis in FEM. The wavelength ($\lambda$) is obtained from the spatial distribution of displacements between position A and B (50 mm) on the acoustic waveguide as shown Fig. 2. The propagation velocity ($v$) was calculated using expression of $v = f \cdot \lambda$ from the relationship between the driving frequency ($f$) and wavelength ($\lambda$). Figure 3 shows the spatial displacement distribution of UY at the driving frequencies of 250 kHz, 160 kHz and 140 kHz.

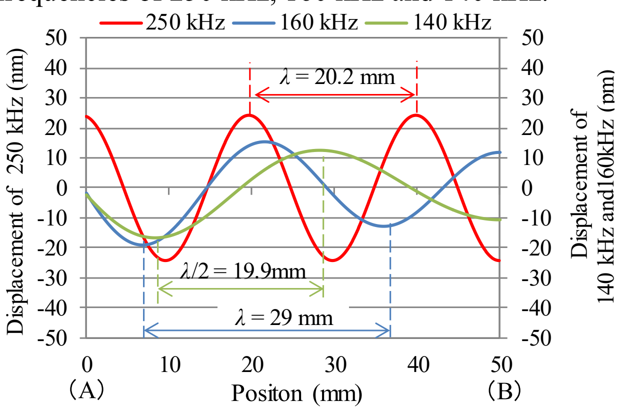


Fig3 Spatial distribution of displacement on the longitudinal wave (UY) of titanium acoustic waveguide (50 mm) when the drive frequency of 250 kHz, 160 kHz, and 140 kHz

## 4. Results and discussions

Figure 4 shows the relationships between propagation velocity in each displacement direction and the driving frequency. The propagation velocity of UX and UZ had increased when the driving frequency increased. The propagation velocities for UX were 544 m/s at driving frequency 110 kHz, 1125 m/s at 500 kHz, respectively. In addition, the propagation velocities for UZ were 225.5 m/s at 110 kHz, 475 m/s at 500 kHz, respectively. On the contrary, the propagation velocity was almost constant and the averaged velocity was approximately 5055 m/s at driving frequency between 200 kHz to 500 kHz. The propagation velocity varied greatly within +/- 10 % between the drive frequency of 130 kHz and 200 kHz. The maximum velocity was about 5600 m/s at 140 kHz, the minimum velocity was about 4650 m/s at 160 kHz. Only two wavelengths or less were included between points A and B on the acoustic waveguide at driving frequency lower than 200kHz. We think that this is the reason for the calculated results of the propagation velocity with unstable fluctuation. It is thought that it is necessary to further study the reason why the calculated propagation velocity fluctuates unstably at the driving frequency lower than 200 kHz.

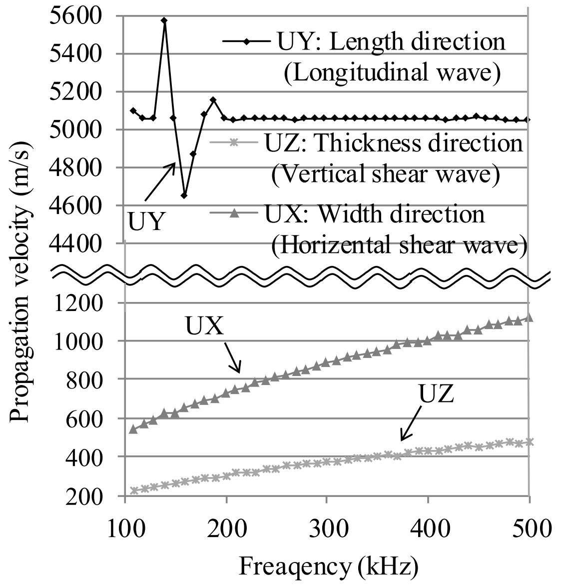


Fig.4 Propagation velocity of the acoustic waveguide in each displacement direction as the driving frequency

## 5. Summary

In this paper, we analyzed the propagation velocity of the elastic guided wave propagating on the straight flat plate acoustic waveguide by three dimensional FEM simulation as the basic consideration for analysis of the CS-USM. For future works, propagation velocity for UY at driving frequency lower than 200 kHz is analyzed by using time domain response analysis. Furthermore, experimental measurement on the thickness direction displacement will be performed, and coiled acoustic waveguide will be analyzed.

## References

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