A MICRO ULTRASONIC MOTOR USING A MICRO-MACHINED CYLINDRICAL BULK PZT TRANSDUCER

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Abstract

In this paper, micro ultrasonic motors using micro-machined cylindrical bulk piezoelectric vibrators are introduced. Cylindrical shaped bulk piezoelectric vibrators, a diameter of 1.0 mm and 0.8 mm and a height of 2.8 mm and 2.2 mm, were developed as stator transducers for traveling wave type ultrasonic motors. We have fabricated a micro ultrasonic motor, a diameter of 2.0 mm and height of 5.9 mm.

Introduction

Micro motors have been receiving increasing attention in realizing various types of micro mechanism applications like micro robots, microsurgery equipments, and micro electro mechanical systems (MEMS). In this paper, micro ultrasonic motors utilizing micro-machined cylindrical bulk piezoelectric vibrators are introduced.

Ultrasonic motors have some merits for the miniaturization of motors. They have simple structure compared with other types of micro actuators, especially electromagnetic motors. In addition, ultrasonic motors need no deceleration mechanism because they have high torque output in low rotation speed. Hence, by using ultrasonic motors, we would realize the micro mechanical system driven by high power actuator.

Many types of micro ultrasonic motors have been reported [1-9]. Some of them used piezoelectric thin film for the acceleration [2, 3, 6, 7]. However they could not realize enough high power output for the drive of micro mechanical systems. To realize high power output, we used bulk PZT vibrator [4].

Structure and Principle

Figure 1 shows the schematic of the piezoelectric cylindrical transducer for the micro ultrasonic motor. Cylindrical shaped bulk piezoelectric vibrators were developed as stator transducers for traveling wave type ultrasonic motors.

Since the stator transducer was fixed at the end of the cylinder, it is easy to support the vibrator and the structure of the motor was not complicated. This is important for micro ultrasonic motor because it is difficult to support the vibrator when the vibrator was miniaturized. Four electrodes on the surface of the cylinder type vibrator were used for the oscillation of the vibrator and the operating vibration mode was the fundamental bending mode [2-4].

Figure 2 shows the analytical result of the vibrator deformation mode calculated by the finite element method. One end of the cylinder was connected to the base, the part which has larger diameter. Another end of the cylinder is deformed.

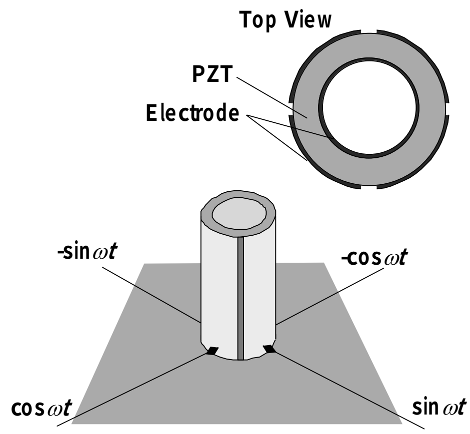

Fig. 1 Schematic of the piezoelectric cylindrical transducer for the micro ultrasonic motor

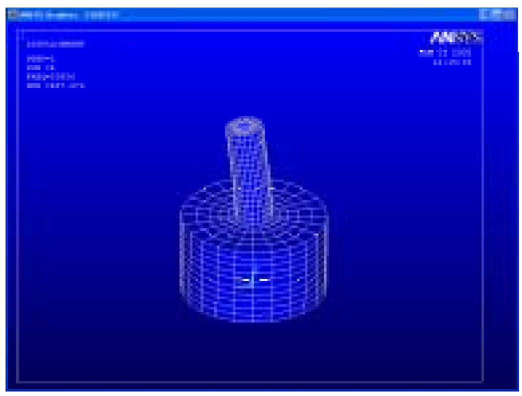

Fig. 2 Analytical result of the Vibrator deformation mode by the finite element method

Fabrication of the Transducer

The stator transducers were fabricated by the micro machining of the bulk cylindrical piezoelectric transducer.

The fabrication process of the stator transducer was shown in Fig.3. The bulk piezoelectric material was cylindrical shaped hard type PZT, C-218 (Fuji Ceramics Co., Japan). The cylindrical ceramics was formed to be a pipe and step like shape by micro machining process. In addition, Ni was plated as electrodes on the surface and inside of the pipe. After the polarization process, the nickel film was divided to four electrodes by the laser beam cutting.

Figure 4 shows the photograph and schematic show of the stator transducer. We fabricated two types transducers. The larger transducer, type 1, is for the macro model of the motor, and the smaller one, type 2, for the micro ultrasonic motor.

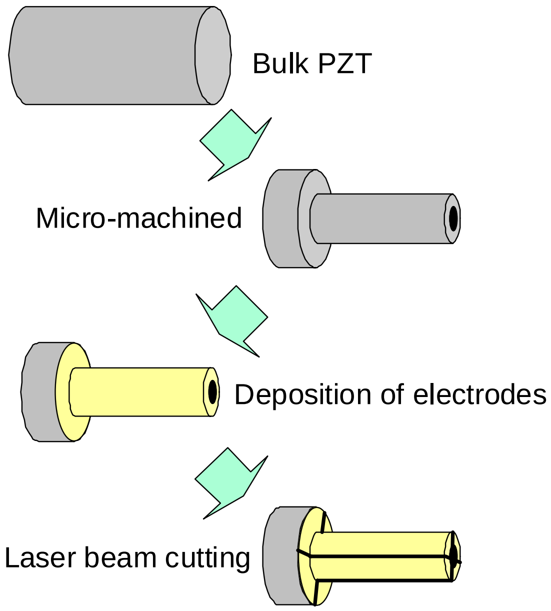

Fig. 3 Fabrication process of the piezoelectric transducer

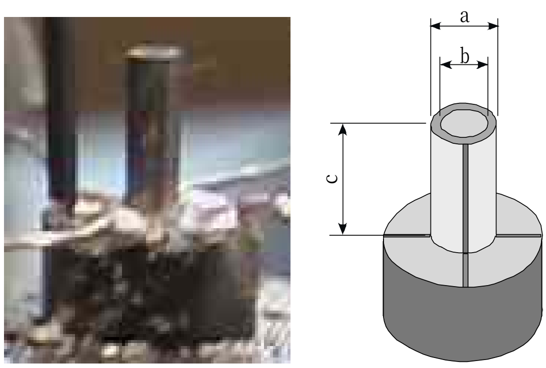

Fig. 4 Photograph and schematic show of the cylindrical bulk piezoelectric transducer

Table I Dimensions of the cylindrical bulk piezoelectric transducers

	Type 1	Type 2
a [mm]	1.0	0.8
b [mm]	0.5	0.4
c [mm]	2.8	2.2

Table I shows dimensions of the cylindrical bulk piezoelectric transducers. The dimensions are a diameter of 1.0 mm and 0.8 mm and a height of 2.8 mm and 2.2 mm.

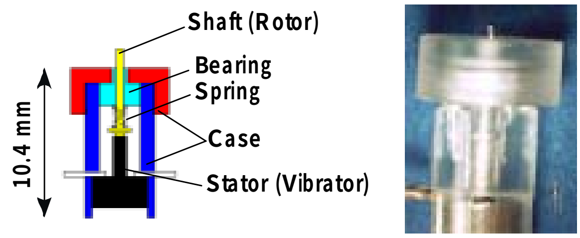

Fig. 5 Cross-sectional view and photograph of the macro model for micro ultrasonic motor using cylindrical bulk piezoelectric vibrator

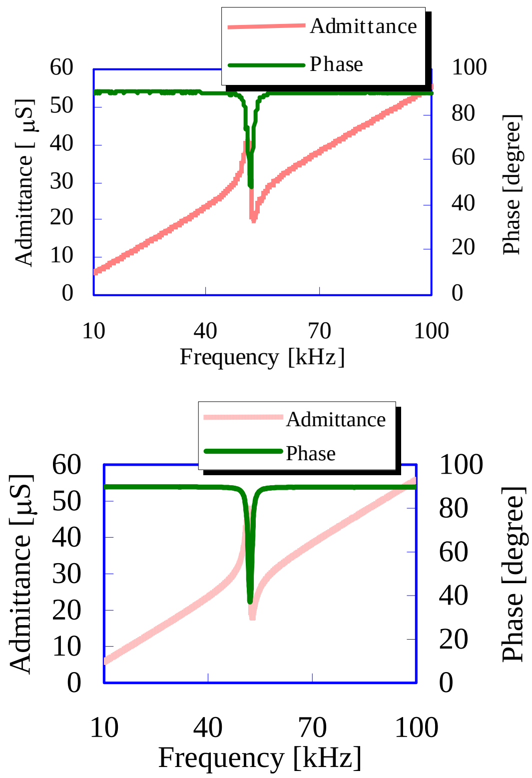

Fig. 6 Relationship between admittance of the vibrator and frequency

Experimental Results

The cross-sectional view and the photograph of the macro model for micro ultrasonic motor using cylindrical bulk piezoelectric vibrator are shown in Fig.5. As shown in the cross-sectional view, the motor consist of a rotor (shaft) made of SUS 630, a bearing made of PTFE, a spring, a stator transducer, and outer cases. The spring I was used as a pre-load mechanism to obtain high torque output. The outer diameter of the case was 7.0 mm.

The vibration properties of the stator transducer were evaluated about the transducer type 1. As shown in Fig.2, the deformed shape and the resonance frequency were estimated by using the finite element method.

Figure 6 shows the relationship between admittance of the vibrator and frequency. Two graphs show the admittance between two electrodes of each direction. The measurement results have the small difference between those of two directions.

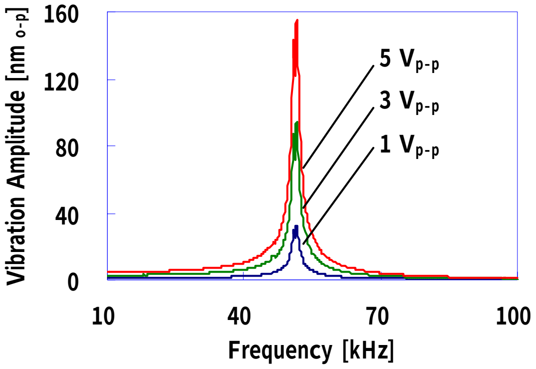

Fig. 7 Relationship between the vibration amplitude at the tip of the transducer Type 1 and the excitation voltage

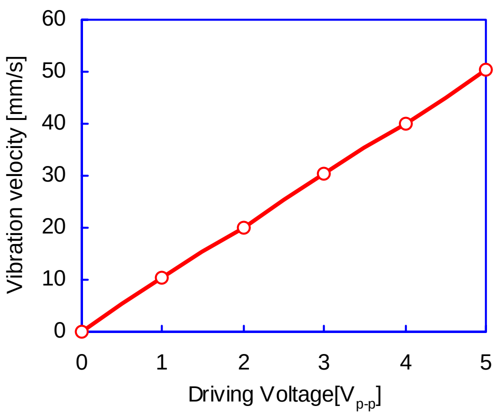

Fig. 8 Relationship between the vibration velocity and driving voltage about the Type 1 transducer

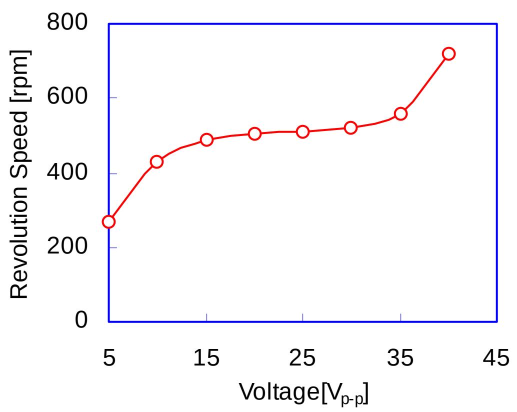

Fig.9 Relationship between the revolution speed of the shaft and the excitation voltage of the macro model

The vibration amplitude of the bending direction at the tip of the vibrator was measured by using the laser Doppler vibrator. Figure 7 shows the relationship between the vibration amplitude at the tip of the transducer Type 1 and the excitation voltage. At the resonance frequency of the larger type vibrator, type 1, the bending direction vibration amplitude at the end of the cylindrical vibrator was 152 $nm_{o\text{-}p}$ at the driving voltage 5 $V_{p\text{-}p}$.

Figure 8 shows the relationship between the vibration velocity and driving voltage about the Type 1 transducer.

It was confirmed that a ruby ball as a rotor was driven as indicated at the resonance frequency of 51 kHz and 77 kHz. The rotational direction could be controlled by changing the polarity of the driving voltage.

Figure 9 shows the relationship between the revolution speed of the shaft and the excitation voltage of the macro model. In this measurement, the pre-load value was only the shaft (rotor) weight. The maximum rotation speed was 720 rpm when the excitation voltage was 40 $V_{p\text{-}p}$. In this measurement, the revolution speed was not saturated and the excitation voltage was not saturated. Hence the limit of the revolution speed would be much higher. The strong non-linearity was shown in Fig.9, the relationship between the revolution speed and the excitation voltage. This relationship would be different when the pre-load value is changed.

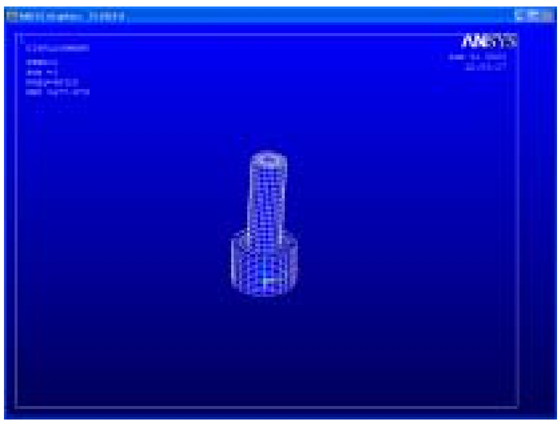

Fig. 10 Analytical result of the deformation mode about the type 2 transducer the using the finite element method

Micro Ultrasonic Motor

A micro ultrasonic motor with pre-load mechanism was also fabricated. As a stator vibrator of this motor, the smaller transducer, type 2, was used.

An analytical result of the deformation mode about the type 2 transducer the using the finite element method is shown in Fig.10. To miniaturize the motor, the base part of the stator transducer must be miniaturized. In this result, the figure shows the deformed shape when the diameter of the base part of the stator is 1.5 mm about the transducer type 2. Figure 11 Relationship between the vibration velocity and driving voltage about the Type 2 transducer used for the micro ultrasonic motor.

The structure of the micro ultrasonic motor using cylindrical bulk transducer and its parts are shown in Fig.12. The diameter of the motor with pre-load mechanism was 2.0 mm, and the height was 5.9 mm. A rotor, whose diameter was 0.8 mm, was pressed to the end of the stator vibrator by using a spring whose diameter was 0.8 mm. An output shaft was united with the rotor, and the diameter of the shaft was 0.4 mm.

Figure 13 shows the micro ultrasonic motor and the piezoelectric vibrator used for the micro ultrasonic motor. We have succeeded in driving this motor and controlling the rotating direction.

Conclusion

We have fabricated micro ultrasonic motors using micro-machined cylindrical bulk piezoelectric vibrators. Cylindrical shaped bulk piezoelectric vibrators, a diameter of 1.0 mm and 0.8 mm and a height of 2.8 mm and 2.2 mm, were developed as stator transducers for traveling wave type ultrasonic motors. We have succeeded in driving this motor and could measure the revolution speed. The maximum revolution per minute was 720 at the driving voltage of 40 V_{p-p}.

Acknowledgement

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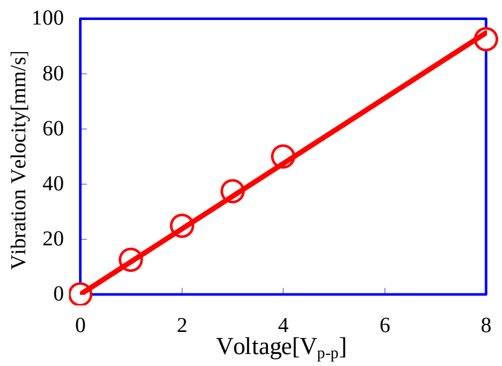

Fig. 11 Relationship between the vibration velocity and driving voltage about the Type 2 transducer used for the micro ultrasonic motor

Fig. 12 Structure of the micro ultrasonic motor using cylindrical bulk transducer and its parts

Fig. 13 Photograph of the micro ultrasonic motor (right) and piezoelectric vibrator (left) on US one cent coin