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A CYLINDRICAL MICRO ULTRASONIC MOTOR USING MICRO-MACHINED PIEZOELECTRIC VIBRATOR

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ABSTRACT

In this paper, a micro ultrasonic motor using micro-machined cylindrical bulk piezoelectric vibrator is introduced. This motor consists of the vibrator, a glass case and a rotor. The diameter of the piezoelectric vibrator was 0.8 mm and that of the motor case was 1.8 mm. Since the stator transducer is fixed at the end of the cylinder, it is easy to support the vibrator and the structure of the motor was not complicated. In addition, the vibrator and rotor were supported by glass case. This is important for micro ultrasonic motor because it is difficult to support the vibrator when the vibrator was miniaturized. We have fabricated and evaluated the cylindrical shaped traveling type micro ultrasonic motor using this vibrator.

Keywords: Micro motor, Ultrasonic motor, Piezoelectric vibrator, Bulk piezoelectric material

INTRODUCTION

There have been many reports about piezoelectric micro actuators. The piezoelectric devices realize micro actuators which have high output power [1]. Among them, especially, ultrasonic motors have simple structure and realize high efficiency.

Some types of micro ultrasonic motor have been fabricated. Ultrasonic motors of cylindrical type [2-7] or disk type [8, 9] are popular. Although the disk type motors have small volume, the output torque was smaller than that of cylindrical type ultrasonic motors.

Deposited piezoelectric thin film was used for the oscillation of micro ultrasonic motor [2, 3]. However it is difficult to generate large output torque. Although a stator vibrator using bulk piezoelectric ceramics can generate larger output force, it is hard to fabricate miniaturized vibrator because the piezoelectric ceramics is brittle material [4]. We have fabricated miniaturized piezoelectric vibrator by micro-machining process [10, 11]. The cylindrical vibrator made of PZT bulk ceramics has an outer diameter of 0.8 mm and inner diameter of 0.4 mm.

PIEZOELECTRIC VIBRATOR

Piezoelectric vibrators for the micro ultrasonic motor were fabricated by using micro machining process [10, 11]. Figure 1 displays the schematic of the piezoelectric vibrator. The vibrator is made of PZT. The bulk piezoelectric material was formed to be a pipe which had a step-shape as shown in Fig.1. To generate traveling wave, there are four divided electrodes on the surface of the outer side of piezoelectric pipe. In the inner side of the pipe, an electrode was also deposited. These electrodes are made of nickel. Four electrodes on the surface of the cylinder type vibrator were used for the oscillation of the vibrator [2].

The dimensions of piezoelectric vibrators in this report are shown in Table I. The vibrator I was used for the stator of the micro motor, and the vibrator II as the evaluation of the vibration properties. Figure 2 shows the cylindrical shaped bulk piezoelectric vibrator, the diameter of 0.8 mm and the length of 2.2 mm This vibrator was developed as a stator vibrator for traveling wave type ultrasonic motor.

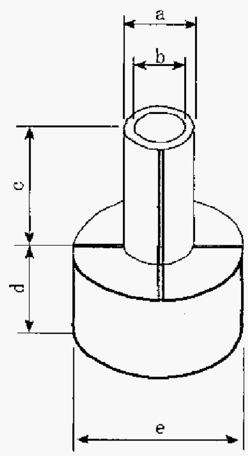

Figure 1 Schenatic of micro-machiened bulk piezoelectric vibrator

Table I Dimentions of piezoelectric vibrators

	Vibrator I	Vibrator II
a (mm)	0.8	1.0
b (mm)	0.4	0.5
c (mm)	2.2	2.8
d (mm)	1.2	2.2
e (mm)	1.3	4.0

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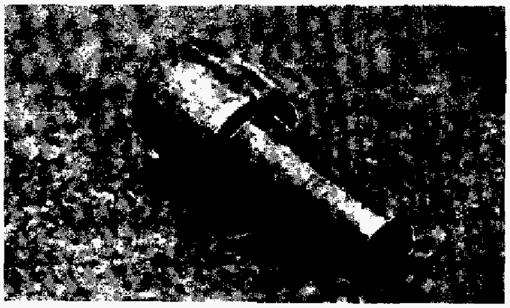

Figure 2 Piezoelectric vibrator (Vibrator I) used for the micro ultrasonic motor

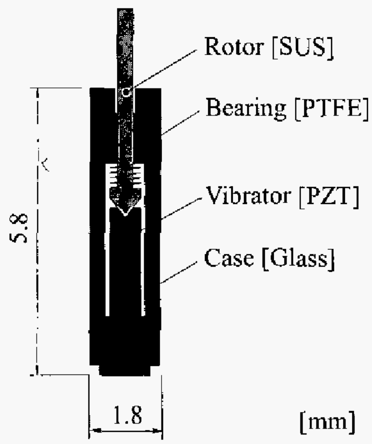

Figure 3 Cross sectional view of the micro ultrasonic motor

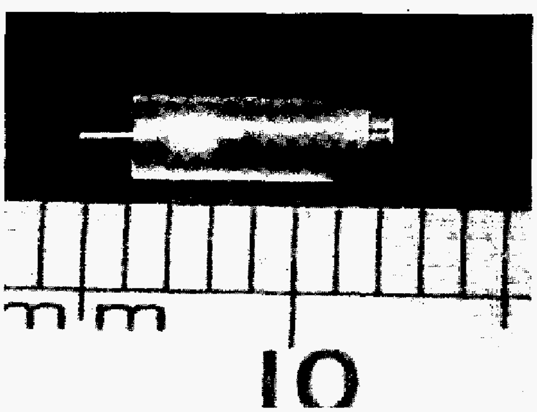

Figure 4 Photograph of the micro ultrasonic motor

MICRO ULTRASONIC MOTOR

Figure 3 illustrates the cross sectional view of the micro ultrasonic motor. The motor consists of a rotor, a bearing, the piezoelectric vibrator, and a glass case. The rotor united with output shaft and the bearing were made of stainless used steel and PTFE, respectively. The piezoelectric vibrator was Vibrator I in Table I. The dimensions of the glass case were the diameter of 1.8 mm and the height of 5.8 mm. Figure 4 shows a photograph of the fabricated micro ultrasonic motor.

The deformed shape and the resonance frequency were estimated by using the finite element method (FEM). Figure 4 displays the analytical result of modal analysis by FEM. The operating vibration mode was the fundamental bending mode. In this condition, the base part of the vibrator and glass case did not deform although the bending vibration was excited at resonance frequency.

The rotation of the motor was evaluated. The surface velocity of the rotor shaft was measured by using a laser surface velocity meter and the revolution speed was estimated. Figure 5 shows the measurement result of the relationship between the revolution speed and the time when the driving started at time = 0. The driving voltage, the pre-load and driving voltage were 40 V_{p-p}, 0.38 mN and 67 kHz, respectively.

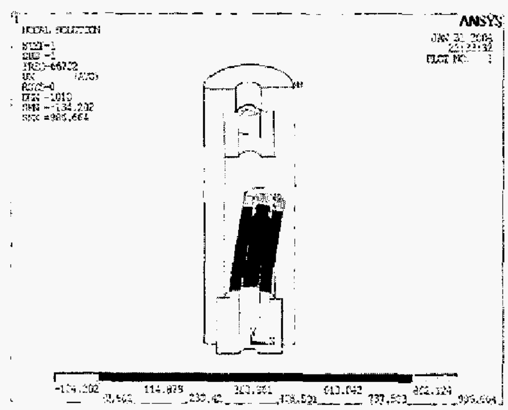

Figure 4 Analytical result of modal analysis by FEM

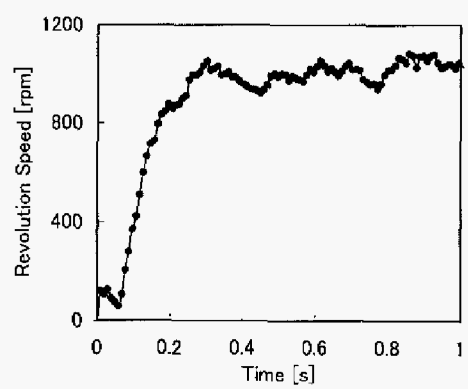

Figure 5 Relationship between the revolution speed and the time; The driving voltage, the pre-load and driving voltage were 40 V_{p-p}, 0.38 mN and 67 kHz

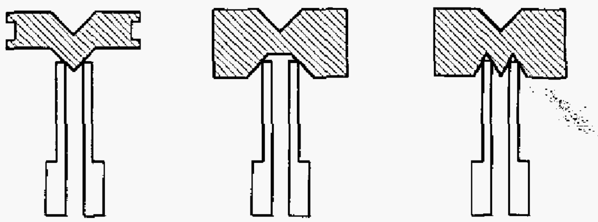

Fig.6 Cross sectional view of experimentally evaluated rotors; rotors 1 - 3 from left to right

The graph of Fig. 5 shows the relationship of the first order lag system between the revolution speed and the time. The saturated revolution speed was 1000 rpm when the driving voltage was 40 $V_{p\text{-}p}$.

EVALUATION OF THE TORQUE

To evaluate the output torque, we used Vibrator II in Table I. This is because the pre-load value can not be changed easily when the glass case was attached to the vibrator as shown in Fig.3. The output torque using this vibrator had been evaluated [11]. However we had not obtained the large torque. To improve the driving condition, we use some types of rotor.

Figure 6 illustrates the cross sectional view of the experimentally evaluated rotors. Three types of rotor were used for the evaluation. The rotor 1 had been already used for the evaluation. This rotor was driven by the inner part of the vibrator. The rotor 2 was generated by the vibration at the outer part of the vibrator. The rotor 3 had a contact with the end of the vibrator, both inner and outer part.

The vibration velocity of the vibrator is important for the characteristics of the ultrasonic motor. The value of vibration velocity has an effect on the revolution speed of the rotor and the output torque. At the cylindrical vibrator, the vibration velocity of the outer part was larger than that of inner part. By using the rotor 2 or 3, the larger torque would be obtained when the rotor 1 was used for the driving.

The starting characteristics were measured to evaluate the effect of the rotors. The surface vibration speed of the shaft which was united with rotor as shown in Fig.3 was measured by using the laser surface velocity meter. The revolution speed of the rotor was estimated from the measured values. The pre-load was given by a spring. The rotor was supported by the needle at the center pivot at upper side. The rotor was pushed by the needle tip and has a contact with the end of the vibrator. The pre-load value was changed by the length of spring [11].

Figure 7 shows the measured starting characteristics of the rotor 2, the relationship between the revolution speed and the time. In this measurement, the driving voltage was changed from 20 $V_{p\text{-}p}$ to 40 $V_{p\text{-}p}$ and the pre-load was constant at 1 mN. Each starting characteristics shows the first order lag condition between the revolution speed and the time.

The starting torque can be estimated from the starting characteristics when there is a first order lag relation between the revolution speed and the time. When T_o [Nm], Ω_0 [rad/s], J [kg m^2], and τ [s] indicate the starting torque, the saturated revolution speed, the inertia of rotor and time constant, the starting torque can be estimated by the equation;

$$T_0 = \frac{\Omega_0 J}{\tau}. \qquad (1)$$

From the experimental results and equation (1), the revolution speed and starting torque were evaluated.

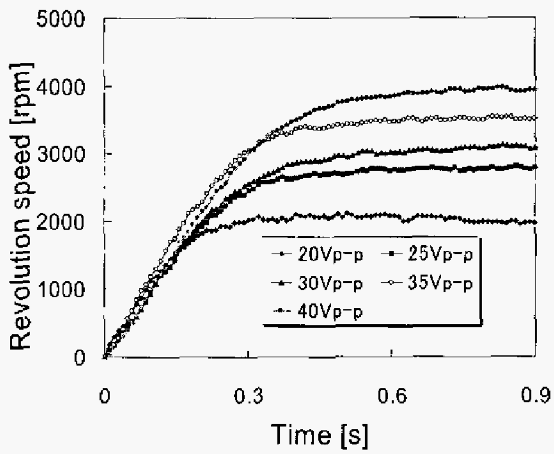

Fig. 7 Relationship between revolution speed and the time when the vibrator II and the rotor2 were used

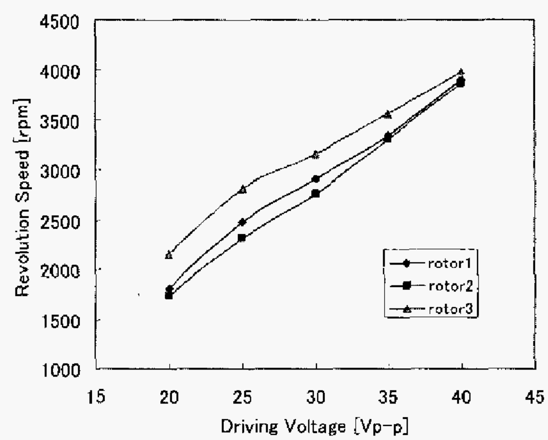

Fig.8 Relationship between revolution speed and driving voltage when the rotors 1 – 3 were used

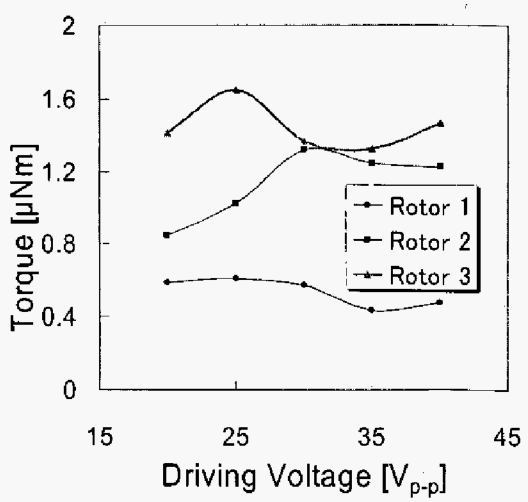

Fig.9 Relationship between the torque and the driving voltage when the rotors 1 – 3 were used

Figure 8 plots the relationship between revolution speed and driving voltage. The vibrator II and the rotors 1 – 3 were used for the driving at the resonance frequency and the pre-load was constantly set at 1 mN. The plots of about rotors 1-3 did not have large difference although the rotor 3 obtained larger values than other rotors.

The values of starting torque were estimated by using measured values and calculated inertia. The results are shown in Fig.9. Figure 9 plots the relationship between the estimated starting torque and driving voltage. The plots of rotor 3 were 3 times larger then those of rotor 1. The largest starting torque was estimated to be 1.6 μNm when the driving voltage was 25 V_{p-p} and the rotor 3 was used.

CONCLUSION

We have fabricated a micro ultrasonic motor which was the diameter of 1.8 mm using a cylindrical shaped piezoelectric vibrator, the diameter of 0.8 mm. The rotation speed and the starting torque were evaluated. To improve the driving condition, three types of rotor were used for the driving. The largest starting torque was 1.6 μNm when the pre-load was 1 mN and the driving voltage was 25 V_{p-p}.

Acknowledgements

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