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Study on a Preload Mechanism for Micro Ultrasonic Motor (2nd Report)

マイクロ超音波モータの予圧機構の開発 (第二報)

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1. Introduction

Ultrasonic motors are expected as the most prominent micro actuator to be used for future micro medical devices such as catheters and endoscopes. They have two advantages for miniaturization: high energy density (high ratio of output to volume) and simple structure [1]. In fact, an ultrasonic motor with diameter less than 5 mm has been practically used for rotating calendar rings in watches. For further miniaturization, several researchers have been prototyping micro-ultrasonic motors that use a bending vibration mode of the stator as the driving principle. These micro motors are constructed of cylindrical stator with a diameter of approximately 1.5 mm and about 5 mm length [2]. The smallest ultrasonic motor uses coupling of axial and torsional vibration modes of the coil stator as the driving principle: A stator with 0.25 mm diameter and 1 mm length is excited by a piezoelectric element and generates the rotation of a sphere [3]. However, total size including magnets for preload is over a few millimeters.

We have built a micro ultrasonic motor using a vibration mode that generates three waves inside the hole of a stator [4]. Fig. 1 shows the prototype micro ultrasonic motor that is consisted of a single metallic cube with a side length of 1 mm and a through-hole of 0.7 mm. Four piezoelectric elements are bonded to the four sides of the stator and generate vibration. This simplicity of the stator makes the manufacturing easy and makes the size small. An output shaft (rotor), which is inserted to the through-hole, generates rotation when AC voltages are applied to the piezoelectric elements and the vibration mode is excited. We have reported that the micro ultrasonic motor could generate large torque when some weights are applied as the preload. However, the size of the preload mechanism using weights is too large in comparison with that of the micro ultrasonic motor.

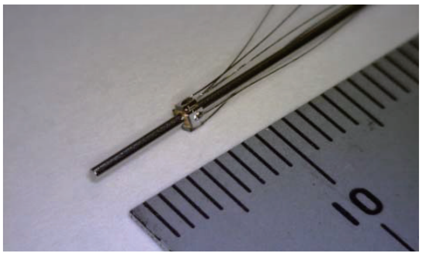


Fig. 1 Prototype of micro ultrasonic motor

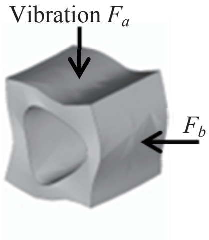


Fig. 2 Vibration mode that generates three waves inside the hole of the stator

Next step is the miniaturization of the preload mechanism attached to micro ultrasonic motors. In this report, we propose a new miniature preload mechanism using a coil spring and clarify the motor output experimentally.

2. Driving Principle

The stator uses a vibration mode that excites three waves along the circumference of the through-hole (three-wave mode). When a vibration F_a acts on the top surface of the stator (a voltage is applied to the top piezoelectric element), three-wave mode, which is a standing wave, is generated as shown in Fig. 2. When the other force F_b acts on the next surface with 90 degrees, the other three-wave mode is excited. By coupling these two three-wave modes with the temporal phase difference of $\pi/2$ which is one-quarter of a cycle, the travelling wave is produced on the inner surface of the through-hole. While producing the traveling wave, elliptical motion is generated on the inner surface of the stator, and this elliptical motion can rotate the rotor.

3. Measurement of the Motor Performance

The preload between the stator and rotor is key factor for improving the motor output. Also, the miniaturization of the preload mechanism is important, not to spoil the size of the micro ultrasonic motor. We build an experimental setup that can examine the relation of the preload to the motor output such as the rotational speed and torque. The stator is installed on the experimental setup as shown in Fig. 3. The rotor with the length of 8 mm and diameter of 0.685 mm is inserted to the stator. As shown in Fig. 3, a bearing is attached to the end of the rotor and a weight is attached to another end as a moment of inertia. To change the magnitude of the preload, an adjustment screw and a coil spring press the bearing in radial direction. The use of this structure can avoid the enlargement of the preload mechanism.

We measure how the torque and rotational speed change when optimizing the preload experimentally. A high speed camera captures the spin of the rotor, and the rotational speed is computed from the change of still images. The output torque is estimated from the angular acceleration and the moment of inertia of the rotor and the weights. The voltages are generated by a function generator, are amplified by two amplifiers, and are applied to the piezoelectric elements of the stator. The voltage frequency and amplitude values are adjustable in those devices.

Fig. 4 shows the transient response of the angular velocity when the voltages with a frequency of 1038 kHz and amplitude of 80 $V_{p\text{-}p}$ are applied. The result shows that the angular velocity reaches its peak value of over 4000 rpm within 20 ms from the rotation start. After steady state is achieved, the change of the angular velocity is observed; this might be because the contact condition between the stator and rotor.

Fig. 5(a) shows the behavior of the torque and revolution when the voltage frequency varies at a constant amplitude of 80 $V_{p\text{-}p}$. The revolution peaks at 1032-1036 kHz. On the other hand, the torque peaks at a higher frequency. This is because large vibration amplitudes make the revolution higher, but a slip occurs between the stator and rotor. The resultant toque becomes higher at lower vibration amplitude. Fig. 5(b) shows that the torque and revolution increase as the voltage amplitude increases. The maximum torque over 30 μNm has been obtained at the voltage amplitude of 140 $V_{p\text{-}p}$. This is very high torque in comparison with the other similar-sized micromotors (e.g. [3]).

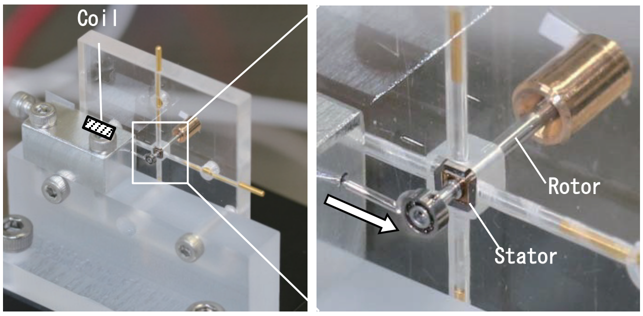


Fig. 3 Experimental setup

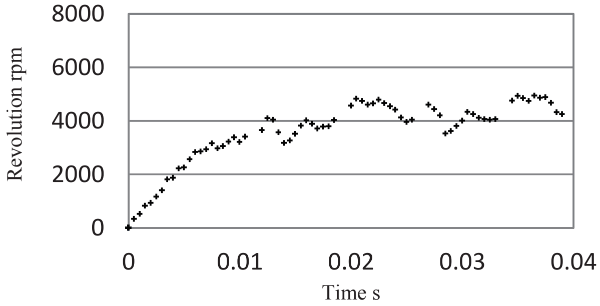
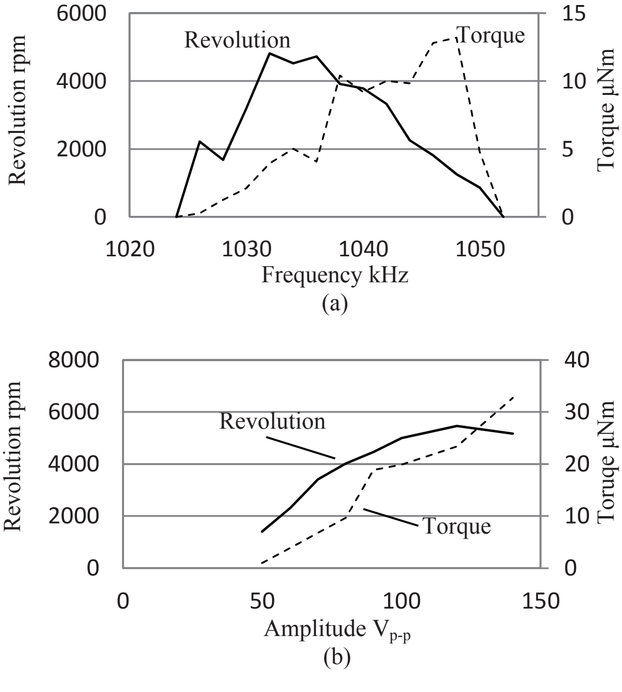


Fig. 4 Transient response



(a)

(b)

Fig. 5 Motor output v.s. (a)frequency and (b)amplitude

References

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