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Preload Characteristic of Micro Ultrasonic Motor using a Stator of One Cubic Millimeter

1ミリ立方メートルのステータを用いた小型超音波モータの与圧特性

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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. 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. In following sections, we briefly describe the driving principle of generating the three waves in the stator and show the recent experimental results of the new prototype.

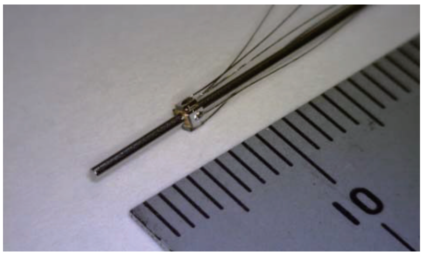


Fig. 1 Prototype of micro ultrasonic motor

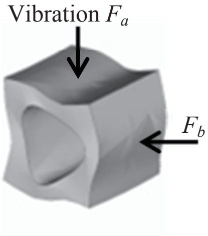


Fig. 2 Vibration mode that generates three waves inside the hole of the stator

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 π/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

Preload between the stator and rotor is key factor for improving the motor performance. We build an experimental setup that can examine the relation of the preload to the motor performances such as the rotational speed and output torque. The stator is installed on the experimental setup as shown in Fig. 3. The rotor with the length of 40 mm and diameter of 0.700 mm is inserted to the stator. To change the magnitude of the preload, weights are attached to the both ends of the rotor as the preload. When there is no weight, the preload equals only rotor's weight (0.119 g). When the all weights are attached to the both ends of the rotor, the preload becomes the maximum value of 0.412 g.

We measure how the torque and rotational speed change by the preloads. 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 with the frequency of 930 kHz are generated by a function generator, are amplified by two amplifiers to 70 $V_{p\text{-}p}$, and are applied to the piezoelectric elements of the stator. These frequency and amplitude stay constant during the experiments.

Fig. 4 shows the behavior of the torque and rotational speed when the preload increases from 0.119 to 0.412 g. The torque increases in proportional to the preload as shown in Fig. 4(a). This is because the increase friction force between the stator and rotor. This behavior of the torque is explained by the Coulomb friction law, which is the famous torque estimation equation of the ultrasonic motor. The maximum torque of approximately 0.8 μNm has been obtained at the maximum preload 0.412 g. This value is practical to rotate small things such as gears in watches. On the other hand, as shown in Fig. 4(b), the rotational speed gradually decreases at the higher preload. It is due to that the increase of the viscosity (damping coefficient) between the stator and rotor.

Another important performance is stability during the steady state of the rotation. After a steady state is achieved, the periodic change of the rotational speed occurs due to roundness of the rotor, change of friction, and vibration of the rotor. When a certain preload is given, the stability is increased by improving the condition between the stator and rotor. Fig. 5 shows how the variation rate, the ratio of the peak velocity and average velocity, is reduced by changing the preload. Without the ring weights, the variation rate is more than 40 %. After ring weights are attached and the preload is increased, the variation rate is much improved to approximately 20 % at the preload 0.412 g.

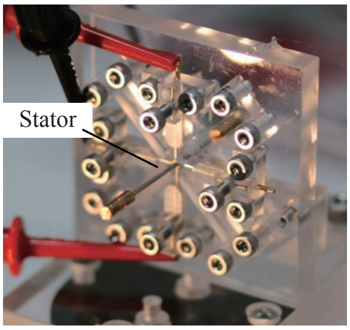
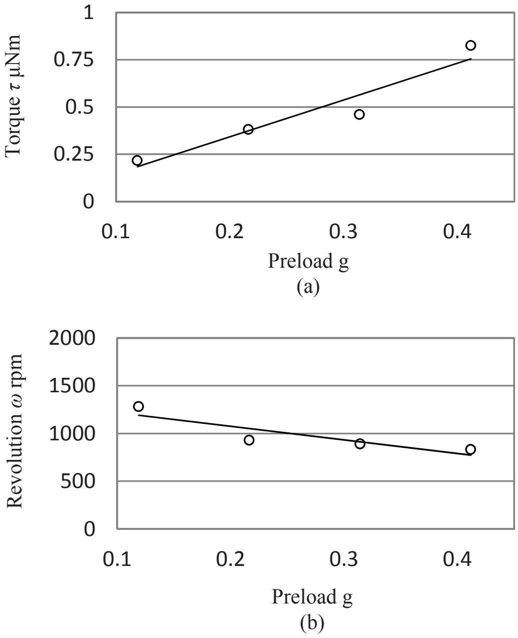


Fig. 3 Experimental setup



(a)

(b)

Fig. 4 The relation of the preload to the torque and rotational speed.

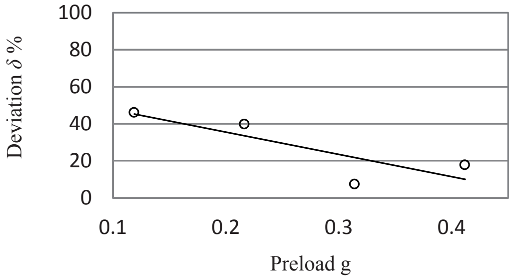


Fig. 5 The relation between preload and variation ratio.

References

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