3J2-2

A high-power ultrasonic motor utilizing torsional/flexural vibrations
ねじり・たわみ振動を用いたハイパワー超音波モータ

Jiang Wu† (Shandong University), Yosuke Mizuno (Yokohama National University), Kentaro Nakamura (Tokyo Institute of Technology)
ウー・ジャン† (山東大学), 水野洋輔 (横浜国立大学), 中村健太郎 (東京工業大学)

1. Introduction

Ultrasonic motors (USMs) convert electrical energy into mechanical energy being based on inverse piezoelectric effect and achieve actuation through frictional force [1]. Recently, rotary USMs have become increasingly demanded in various fields [2,3], e.g., robots' arm joints, assist units, and optical devices. In order to broaden the application areas of rotary USMs, their torque densities and power densities needs enhancement.

It is known that the vibration modes and the structures of the vibrators of rotary USMs greatly affect the torque densities and power densities. Most rotary USMs work in the orthogonal bending (B^2) modes [2], but the poor electromechanical coupling of bending vibration limits the torque and output power of USMs. Similar to the B^2 ones, the bending/longitudinal USMs show insufficient output since they utilize bending vibration to drive the rotors [4]. On the other hand, several rod-shaped USMs utilize torsional/longitudinal vibrations because the torsional vibration are powerful [5]. However, in most cases, the rotors are driven with the end surfaces; this structure limits the driving-feet distance and consequently causes low output. It would be meaningful to test USMs working in other vibration modes to overcome the aformentioned shortcomings.

In this study, we develop a torsional/bending (T/B) vibrator in rod shape to form a rotary motor. Here, the torsional vibration is used to generate the driving force for its good electromechanical coupling, and the bending mode generates the normal force. Meanwhile, since two elleptical motions in opposite directions are obtained on bilateral ends, the rotor is pressed onto the circumferential surface to achieve the rotation. Considering these features, the T/B motor possibly exhibits relatively high torque density and high power density compared to the conventional USMs. However, our proposal needs to be experimentally verified.

2. Configuration

Fig. 1 schematically shows the developed vibrator, which comprises several groups of PZT disks and cylindrical vibrating bodies. The vibrator is 34 mm in outer diameter and 110 mm in length.

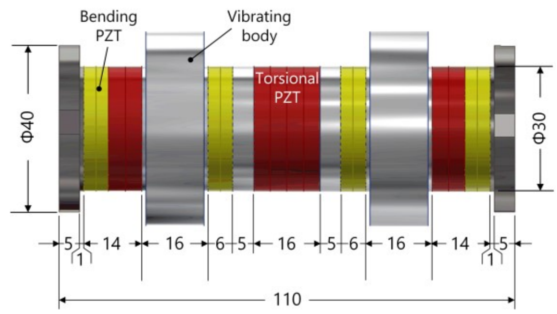

Fig. 1 Schematic of the developed vibrator.

Fig. 2 illustrates the working principle:

Step (1): at $t = nT$ (where t, n, and T are respectively the time, an integer, and the period), the torsional vibration velocity along the horizontal direction reach the peak value. Meanwhile, the vertical vibration displacement is maximal. The vibrator frictionally accelerates the rotor at the time.

Step (2): at $t = (n + 1/4)T$, the torsional vibration velocity and the vertical vibration displacement are zero.

Step (3): at $t = (n + 1/2)T$, the torsional vibration velocity and the vertical vibration displacement are the peak values in the negative direction.

Step (4): at $t = (n + 3/4)T$, the torsional vibration velocity and the vertical vibration displacement, similar to those in step (2), are zero.

The vibrator decelerates the rotor in steps (2)-(4).

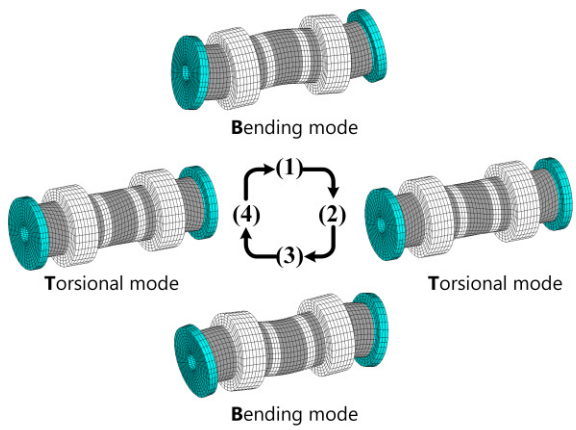

Fig. 2 Working principle.

3. Experimental results

Figs. 3(a) and **(b)** show the rotation speed and the output power as functions of the torque, respectively. The applied voltage and the working frequency are respectively set to 300 V and 21.68 kHz. At the preload of 650 N, the maximal rotation speed reached 125 r/min, while it decreased to 100 and 65 r/min, respectively, when the preloads increased to 1220 and 1690 N. The maximal torque reached 10 Nm. At 1220 N, the maximal output power was 40 W, higher than the values corresponding to the preloads of 650 and 1690 N.

Fig. 4(a) plots the maximal torques against the vibrators' weights. Clearly, the torque density of the T/B motor reaches 20 Nm/kg, exceeding the values of most conventional USMs with other vibration modes. As shown in **Fig. 4(b)**, the power density reaches 76 W/kg, relatively high compared to most rotary motors. As predicted, the experimental results verify the effectiveness of our proposal.

4. Conclusion

In this study, a rotary motor with the T/B mode is developed and its load characteristics are tested. The torque densities and power densities of the T/B motor are respectively 20 Nm/kg and 76 W/kg, higher than those of most conventional rotary USMs. In the future, we will structurally optimize this motor to further improve its performance.

Acknowledgment
This work was supported by JSPS KAKENHI 17J05057.

References

1. S. Ueha, Y. Tomikawa, M. Kurosawa, K. Nakamura: *Ultrasonic Motors-Theory and Applications*, p. 4-13.
2. J. Wu, Y. Mizuno, K. Nakamura: *IEEE Trans. Ind. Elect.* **67**, 6762 (2020).
3. J. Wu, Y. Mizuno, K. Nakamura: *IEEE Trans. Mechatronics* **23**, 788 (2018).
4. Y. Goda, D. Koyama, K. Nakamura: *Jpn. J. Appl. Phys.* **48**, 07GM06 (2009).
5. K. Nakamura and S. Ueha, *Electron. Commun. Jpn. II* **81**, 57 (1998).

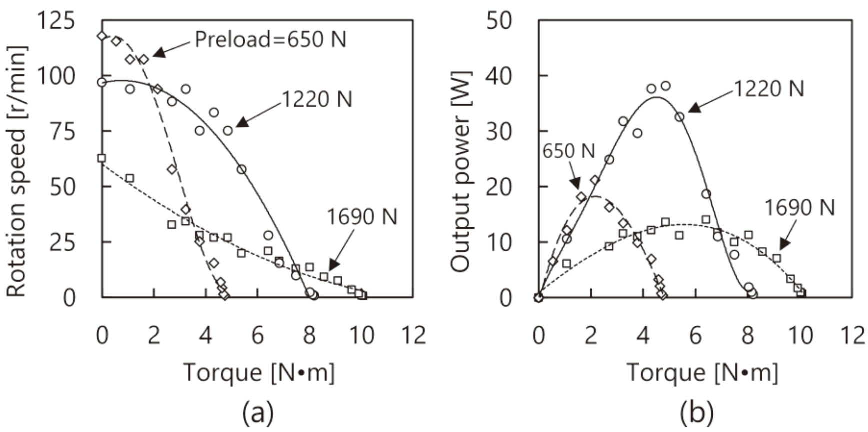

Fig. 3 Load characteristics: (a) rotation speed and (b) output power as functions of torque.

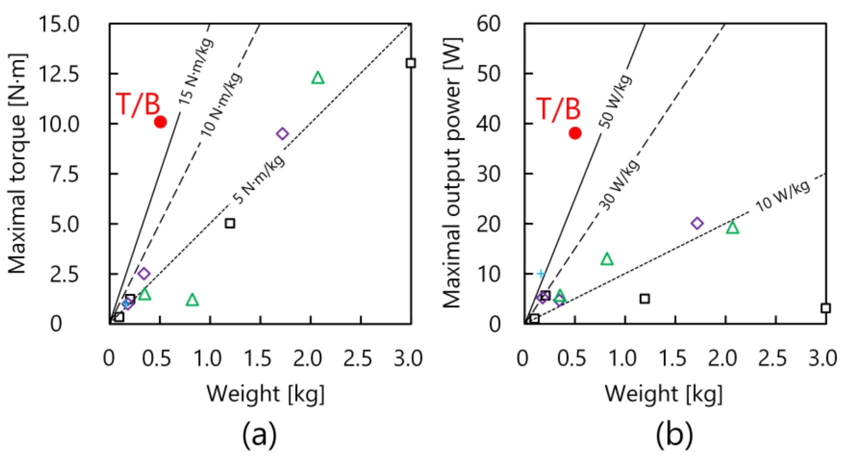

Fig. 4 (a) Maximal torques and (b) maximal output powers versus the vibrators' weights.