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Proceedings of Symposium on Ultrasonic Electronics, Vol. 35 (2014) pp. 199-200
3-5 December, 2014

# A Traveling Wave Ultrasonic Motor Using Polymer-based Vibrator

ポリマー振動子を用いた進行波超音波モータ

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## 1. Introduction

Having natures of low speed, high torque and quick response characteristics, ultrasonic motors (USM) are applied in robot, precision machine and optical instruments. A lightweight actuator is essential to decrease the total weight and increase the operability. Although USMs, in general, are superior to conventional electromagnetic motor in torque/weight ratio, lighter motor is demanded. In this research, we mainly focus on using low density materials to decrease weight. In recent reports, by making USM with polymer-based bending vibrator and measuring its mechanical characteristics, we knew that, comparing with metal-based ones, USMs with polymer-based vibrator has higher rotary velocity and lower maximum torque [1], polyphenylenesulfide (PPS) can be considered as the most appropriate polymer among tested ones. However, the driving frequency of the bending vibrator was approximately 4.5 kHz. It should be confirmed whether mechanical loss is low enough and polymer-based USM can be driven within ultrasonic frequency range experimentally. In addition, as one important parts in USM, contacting surface and rotor also have influence on the motor's performance, thus, material is worthy of being chosen carefully.

Aiming at solving these problems, in this paper, we examined a PPS-based annular vibrator and several disk-shaped rotors made of different materials to form traveling wave USMs, and measured the vibration and mechanical characteristics to answer the questions mentioned above.

## 2. Material and Method

Figures 1 and 2 depict the structure and dimensions of vibrator. Elastomer of vibrator is made of PPS, whose mechanical parameters are listed in Table 1. One piece of annular piezoelectric ceramic (C213, produced by Fuji ceramics Corp., Japan) is glued on the bottom of the PPS ring, whose electrodes are divided into five wavelengths along the circumference. The polarization

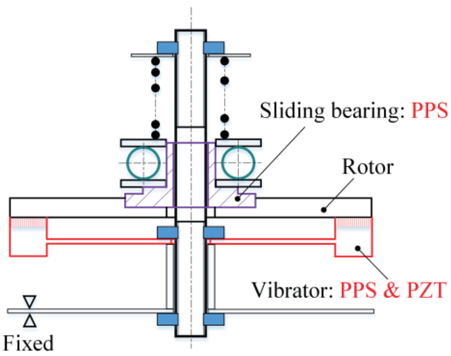


Fig. 1 Structure of the traveling wave USM

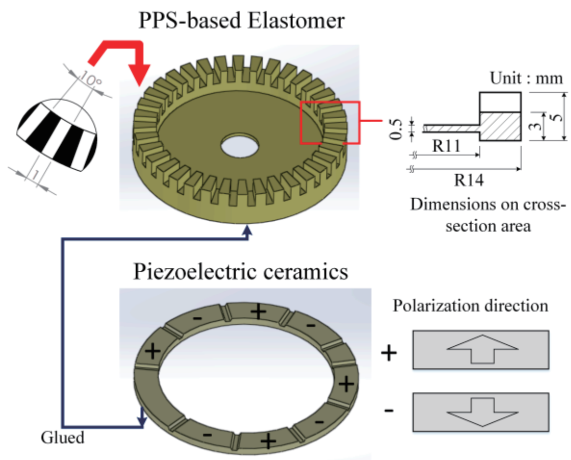


Fig. 2 Structure and dimensions of the PPS-based vibrator

Table 1 Mechanical parameters of the tested PPS

| Mechanical parameters | Value |
|---|---|
| Density ($\times 10^3$kg/m$^3$) | 1.35 |
| Elastic modulus (GPa) | 3.45 |
| Poisson's ratio | 0.36 |

directions alternate every half wavelength and two parts with length of 1/4 and 3/4 wavelengths are set without polarization to generate vibrations with spatial phase-difference. Being separated by 1/4 and 3/4-wavelength slot, piezoelectric ceramics are divided into two groups, with sinusoidal driving voltage exerting on different groups, two standing waves with 90-degree phase difference in space, sin($kx$) and cos($kx$) are generated, respectively. Here, $k$ is the wave number. When two channels of

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voltage with 90-degree phase, sin($\omega t$) and cos($\omega t$), are exerted on the different groups simultaneously, a travelling wave will be generated. Thus, a rotor pressed on the top of vibrator will be driven by the travelling waves.

Because one of the objectives in this experiment is to find suitable material for rotor, rotors are made of polyetheretherketone (PEEK), polyacetal (POM), PPS, aluminum and stainless steel. The driving frequency, zero-to-peak voltage and phase between them are 28.82 kHz, 180 V(two channels) and 70 degrees. Using the experiment system shown in Fig. 3, we measure the rotation speed for different load.

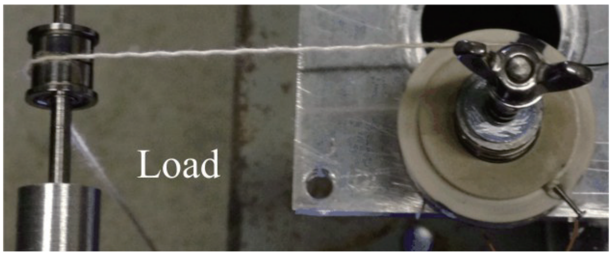


Fig. 3 Experimental system for the evolution of mechanical characteristics

## 3. Results

In order to discuss on the performance, we summarized the mechanical characteristics under approximately the same preload in Fig. 4. The conclusions are:

(1) USM with the PPS-based rotor has larger angular velocity than other ones when the load is lower than 100 μNm;

(2) USMs with the metal-based rotor have larger torque than the polymer-based ones. Maximum torque is determined by preload, friction coefficient and arm length (the distance between the action point and the axis). As the arms are same in all experiments and preload is set at the same level, maximum torque is mainly determined by the friction coefficient

$$\mu = \frac{T_{max}}{F \cdot r},$$

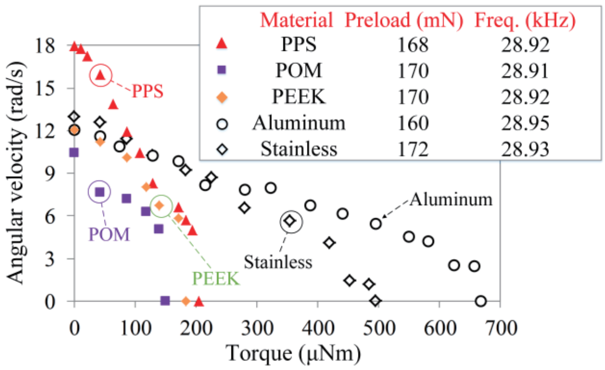


Fig. 4 Mechanical characteristics of the USMs with polymer-based rotors under the preload of approximately 170 mN

where, $T_{max}$, $F$, $r$ represent the maximum torque, preload, arm (11 mm), respectively. Here, using Eq. 1, we calculate friction coefficient between PPS and rotor materials. It should be noted that these results show the friction coefficients under ultrasonic vibration, which will be different more or less from that measured without vibration.

Table 2 Friction coefficients under ultrasonic vibration status between PPS and rotor materials

| Rotor material | PPS | POM | PEEK |
|---|---|---|---|
| Friction coefficient | 0.111 | 0.081 | 0.099 |
| Rotor material | Aluminum | Stainless | |
| Friction coefficient | 0.380 | 0.263 | |

(3) As the USM with aluminum-based rotor has larger torque and output power than other ones, aluminum is considered to be the most appropriate material to form contacting surface in USM with PPS-based vibrator. Throughout this experiment, we used aluminum as rotor material, which directly contact to the vibrator. However, in practice, the rotor body should be made of polymer because of its low density and an aluminum-based annular thin sheet as friction material should be attached on the bottom of the polymer-based rotor.

## 4. Conclusions

In order to test whether polymer-based USM can be driven or not within ultrasonic frequency and find appropriate material as rotor, in this paper, we made traveling wave USMs with annular PPS-based vibrator and rotors produced with PPS, POM, PEEK, aluminum and stainless steel, measured and evaluated their vibration and mechanical characteristics. The following conclusions can be drawn:

(1) Polymer-based USMs had nature of quietness as conventional ones under driving frequency of 28.8 kHz;

(2) USM with PPS-based rotor has the largest angular velocity under low load, and USMs with metal-based rotor have far larger maximum torque than that with polymer-based rotors;

(3) Aluminum is suitable material to form contacting surface of rotor if PPS-based vibrator is used. As a result of low density, polymer is suitable for rotor, considering the light weight of USM.

## Acknowledgment

The authors would like to thank Corporation Daicel for providing polymer materials.

## References

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