3P-41

Proceedings of Symposium on Ultrasonic Electronics, Vol. 31 (2010) pp. 537-538
6-8 December, 2010

Characteristics of Noncontact Ultrasonic Motor with Double Disk Rotor Using Acoustic Coupling

音響結合を利用した２重円板ロータをもつ非接触型超音波モータの特性

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1. Introduction

We have been studying on noncontact ultrasonic motors which do not use the friction force [1-2]. The rotor in these motors rotates without making contact with the stator by maintaining the narrow air gap between the stator and the rotor. Recently, we have reported the rotational characteristics of the noncontact ultrasonic motor over whose rotor the acoustic reflector was mounted [2]. They have been improved by using the acoustic streaming in not only the lower air gap but also the upper air gap of the rotor. It is presumed that the acoustic streaming in the upper air gap is generated by the acoustic coupling between the two air gaps. This paper reports the rotational characteristics of the noncontact ultrasonic motor with the double disk rotor using the acoustic coupling between the two air gaps.

2. Construction of motor

Figure 1 shows the construction of the noncontact ultrasonic motor using a flexural vibration disk. The rotor consists of the two disks of the same size and a shaft which rotates together with them. Besides the air gap (gap-1) between the stator and the rotor, another air gap (gap-r) with the distance of g_r is formed between the two disks of the rotor. The gap distance g_1 between the stator and the rotor is kept constant during the rotation of the rotor. When a circumferential flexural traveling wave vibration is excited in the disk stator, the rotor rotates without making contact with the stator. **Figure 2 (a)** shows the vibration patterns of the stator in each of which there are three nodal lines and one nodal circle of a $0.85D_s$ diameter. These two degenerating resonant modes are driven with the different phases separated by 90° to excite a circumferential flexural traveling wave vibration. **Figure 2 (b)** shows the structure of the stator. The stator is constructed by bonding an aluminum disk of 30 mm outside diameter (D_s), 1 mm inside diameter, and 0.4 mm thickness on a lead zirconate titanate (PZT) disk of 30 mm outside diameter, 1 mm inside diameter, and 0.15 mm thickness, which is polarized in the thickness direction. Four electrodes for exciting individually each one of the two vibration modes shown in Fig. 2 (a) are formed on the undersurface of the PZT.

3. Experimental results

The rotational characteristics were measured under the condition that the constant input power of 60 mW was applied to each one of the four electrodes. The double disk rotor which was made of the two acrylic resin disks of 26 mm diameter (D_r) and 1 mm thickness (t_r) and a shaft of 0.9 mm diameter was used for the measurement. The driving frequency of the stator was about 26 kHz.

Figure 3 shows the revolution speed of the rotor measured as a function of g_1. To reveal the influence of g_r, the measurement was conducted using the double disk rotor whose g_r was adjusted

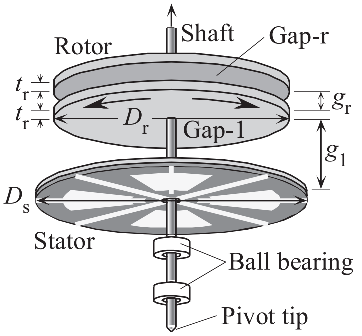
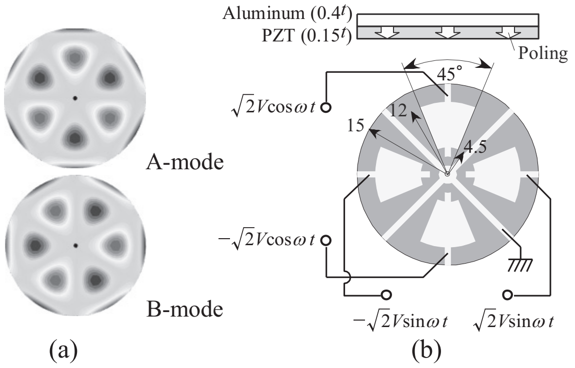


Fig. 1　Construction of noncontact ultrasonic motor with double disk rotor.



(a)　(b)

Fig. 2　(a) Vibration patterns and (b) structure of stator.

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by sliding the upper disk of the rotor. To compare, the characteristics measured using the conventional rotor constructed from an acrylic resin single disk of 26 mm diameter and 2 mm thickness are shown by the broken line in Fig. 3. All rotors shown in Fig. 3 are the same weight. The revolution speeds of the double disk rotors were almost similar to that of the single disk rotor in the narrower g_1 range than about 0.1 mm but fully exceeded except for g_r of 0.2 and 5.0 mm that of the single disk rotor in the wider g_1 range than about 0.1 mm. The double disk rotor with g_r of 0.8 mm rotated fastest at g_1 of about 0.4 mm, and its maximum revolution speed was about 1.5 times higher than that of the single disk rotor. The g_1 for the double disk rotor to obtain the maximum revolution speed was larger than 0.2 mm for the single disk rotor. Furthermore, the double disk rotors with g_r of 0.8 or 1.0 mm rotated at the higher revolution speed than 1000 rpm in the wide g_1 range up to at least 1.5 mm. We expect that the acoustic streaming induced in the air gap between the two disks of the double disk rotor contributes to the improvement of the revolution speed. The characteristics of the double disk rotor with g_r of 5.0 mm were almost similar to the single disk rotor. It is presumed that the intense sound field to induce the acoustic streaming is not generated in the air gap of such wide g_r as 5.0 mm. The double disk rotor with the narrow gr such as 0.2 mm rotated faster than the single disk rotor at the wider g_1 range than 0.4 mm, but the characteristics in the narrow g_1 range were a little down.

To clarify the effect of the rotor's air gap, we measured the characteristics of the double disk rotor the gap-r of which was closed by a thin paper attached in the circumference of the two disks of the rotor. The characteristics of the double disk rotor of g_r = 1 mm with the closed air gap were almost similar to that of the single disk rotor shown in Fig. 3. We expect that the sound field and the acoustic streaming are not induced in the gap-r because the gap-r is acoustically isolated from the outside sound field. This experimental result confirms that the origin of the sound field generated in the gap-r is the acoustic coupling from the outside sound field. The reason for not having much effect on the revolution speed in the narrower g_1 than 0.1 mm will be that the outside sound field of the air gap is very weak because the sound field in the very narrow air gap is hard to leak to the outside from the open edge.

We observed the movement of the lycopodium put into the gap-r to investigate the air flow in the gap-r. **Figure 4(a) and (b)** are the photographs of the quarter part taken from the upper side of the transparent double disk rotor. The g_1 and g_r were adjusted to 0.4 and 1.0 mm, respectively. The rotation of the rotor was stopped to observe the movement of the lycopodium by only the air flow. When the stator was driven by the voltage sources with the phase difference of 90°, the lycopodium was blown off and then transported in the circumferential direction with high speed as shown in Fig. 4(b). The lycopodium in the radius region from about 8 to 11 mm was especially intensely flowed. The flowing direction of the lycopodium coincided with the rotation direction of the rotor observed in the experiments. When the g_1 was changed from 0.4 to 0.1 mm, the recognizable transportation in the circumferential direction of the lycopodium could not be confirmed. We consider that the lycopodium is blown off by the acoustic streaming induced in the gap-r and the strong sound field in the gap-r to induce it originates in the acoustic coupling between the gap-1 and the gap-r.

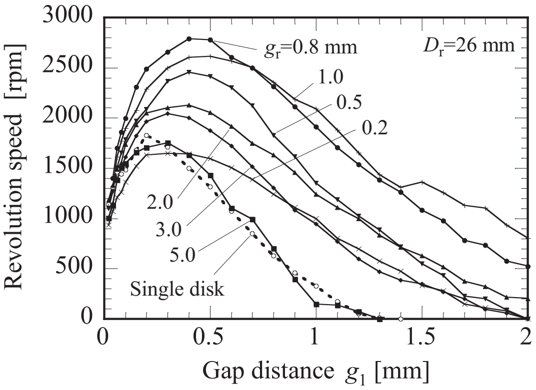
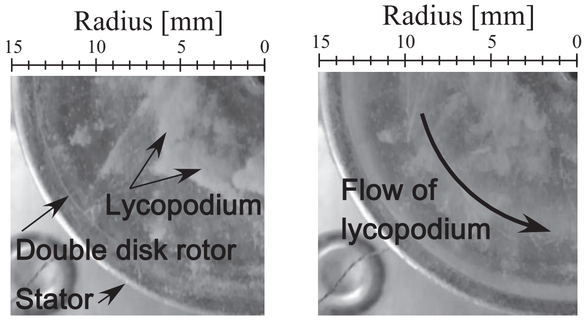


Fig. 3 Revolution speed characteristics as a function of gap distance between stator and rotor.



(a) Before driving (b) During driving

Fig. 4 Air flow in gap between two disks of rotor.

4. Conclusions

The improvement of the rotational characteristics for the noncontact ultrasonic motor have been realized by using the double disk rotor which can utilize the acoustic streamings in air gaps between not only the stator and the rotor but also the two disks of the rotor.

References

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