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Development of rotary-type noncontact-stepping ultrasonic motor

回転型非接触超音波ステッピングモータの開発

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1. Introduction

A flat object can be levitated with small gap from an ultrasonic vibration plate. This phenomenon is called near-field acoustic levitation, and it has been studied for the application such as a noncontact transportation and noncontact ultrasonic motor[1]. The levitated object is transported by a viscous force of acoustic streaming generated between vibrator and levitated object.

The objective of this study is to investigate the possibility of a noncontact-stepping ultrasonic motor (NCS-USM) using the rotational force by acoustic streaming. This paper reports the construction of the rotary-type NCS-USM, behaviors of a rotor, and simulated and measured rotational torques.

2. Operating principle

Figure 1 shows that an object levitated above two vibration sources is transported toward the vibration source with larger amplitude by difference in strength of viscous force yielded from acoustic streaming, and then the object stays above the vibration source when both vibration sources have different amplitude. It is possible to apply such an operating principle to rotary transportation. A rotor installed above multiple stators arranged circularly can be rotated as shown in **Fig. 2**.

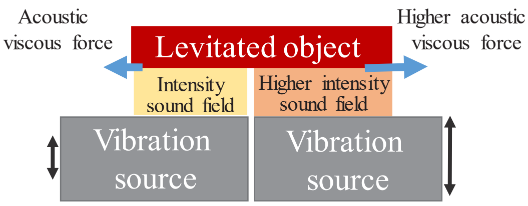

Fig.1 Operating principle of NCS transportation.

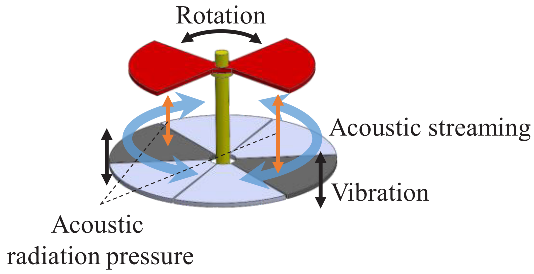

Fig.2 Arrangement of stepping motor and operating principle of rotation by acoustic streaming.

3. Finite element analysis results

The rotational force of the rotor was simulated by acoustic-structure interaction analysis and fluid-structure interaction analysis using finite element analysis software (COMSOL Multiphysics 5.3)[2]. **Figure 3** shows the model of analysis. Six fan-shaped stators, made of duralumin, arranged circularly, and a fan-shaped rotor made of acrylic was installed above them via air gap (0.2mm). **Figure 4** shows dimensions of the stators and the rotor. The center angle of the rotor is about 20°. This is larger than that of the stators. Therefore the rotor is always above the multiple stators at any position.

Figure 5 shows the analysis range. Only one of stators was drove with an amplitude of 4.4μm. The vibration distribution has two vibration nodal lines in the circumferential direction and one vibration nodal arc in the radial direction. The position where the left end of the rotor overlaps with the right end of the driving stator is defined as θ=0°, and the analysis was carried out in the range where the rotor was rotated counterclockwise by 2° to θ=70°.

Figure 6 shows the analysis result of the rotational torque acting on the bottom surface of the rotor. The rotational torque acts in the direction where the driving stator is put until the left end of the rotor overlaps with the left end of the driving stator (θ=60°), but the direction of the rotational torque reverses at θ=60° as the border. Therefore, a holding force acts on the rotor at θ=60°.

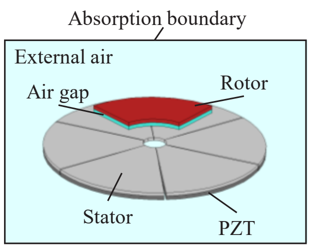

Fig.3 Model of finite element analysis.

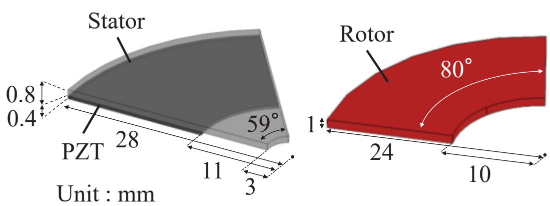

Fig.4 Dimensions of stator and rotor.

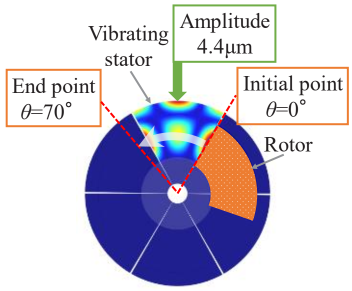

Fig.5 Analysis range.

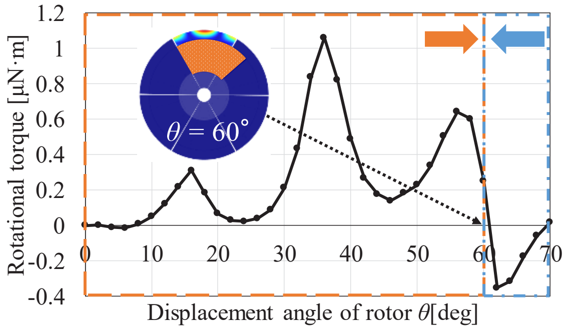

Fig.6 Analysis results of rotational torque

4. Experimental result

In the experiments, six fan-shaped stators were formed by slitting a duralumin disk radially, but the central part of the disk was not cut off completely. Therefore the stators were integrated around the center of disk. Such a construction prevents the positional deviation and inclination among the stators. Two fan-shaped rotors were symmetrically connected with a bar, and the center portion of the bar was connected to a rotary shaft. Two stators which were arranged to the position symmetrical with the rotation mutually were driven at their resonance frequencies, which were 28.9 kHz and 29.7 kHz, respectively, and they were driven with the amplitudes in which the outer end of them were 4μm. The distance between the stator and the rotor was 0.2mm, and the initial position was defined as the position where the rotor slightly overlapped with the driving stators.

Figure 7 shows the initial and final positions of the rotor. As the stators were driven, the rotor rotated in the direction of the driving stators, and the rotor stopped at the position where the end of the rotor overlapped with the boundary of stators after the rotor repeatedly swung. **Figure 8** shows an example of the transient response of the displacement angle of the rotor measured by image processing. The rotor swung with a damped vibration, and then stopped at θ=60°. Using this result, change in angular acceleration was calculated. **Figure 9** shows the result of comparison between normalized angular acceleration calculated from the measured displacement angle of the rotor and simulated rotational torque. Changes in the displacement angle in both cases approximately corresponded from each other. Hence the validity of the analysis results was obtained, and the performance of the rotary-type NCS-USM can be estimated.

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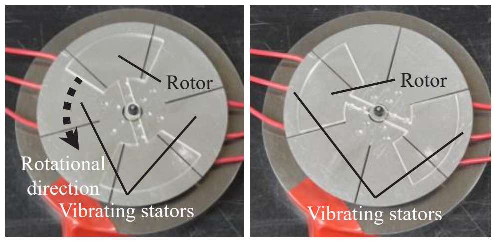

(a) Initial (b) Final

Fig.7 Rotor positions during operation.

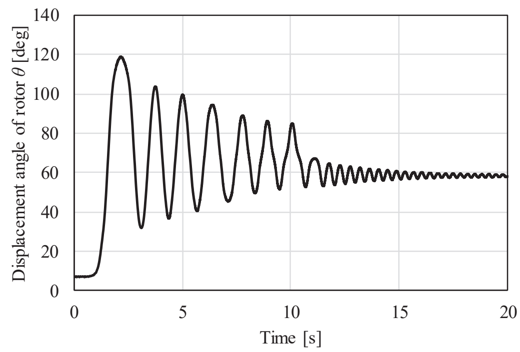

Fig.8 Measured transient response of displacement angle of rotor.

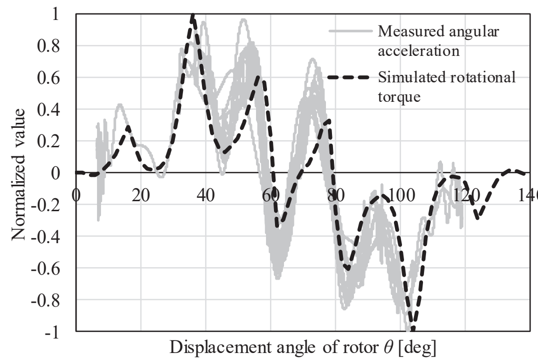

Fig.9 Comparison between measured angular acceleration of rotor and simulated rotational torque.

5. Summary

In the rotary-type NCS-USM composed of the stators arranged circularly and the flat plate rotor above them, the rotor rotation could be confirmed by the simulation and measurement. Since the rotor stopped above the driving stators, the rotor could be rotated as a stepping motor by switching a pair of driving stators. Hereafter, it is necessary to consider the optimum driving method as a stepping motor.

References

1. R.Yano et al., JJAP, 50, 07HE29, 2011.
2. Wada et al., Acoust. Sci. Tech., 1047-1048, 2017.