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Examination of high output sandwich-type annular spherical ultrasonic motor
サンドウィッチ型円環球面超音波モータの高出力化の検討

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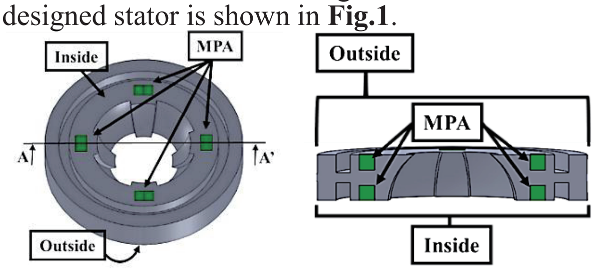
1. Introduction

In recent years, the research field of robotics has been developing, so that an actuator system with multi-degree-of-freedom(MDOF) of motion and complicated actions such as joints or eyes have been researched and developed. The authors also have developed sandwich-type MDOF spherical ultrasonic motor(SUSM)[1-2)]. The motor consists of a spherical rotor which is held between two stator vibrators. The stator vibrator excites three kinds of vibration modes, and the spherical rotor can rotate on three axes. The purpose of this research is to increase the torque of MDOF-SUSM using annular stator vibrator.

In this paper, the examination of a high output by multilayer piezoelectric actuators(MPAs) is described. A new structure of the annular stator vibrator embedding MPAs is designed for strong excitation of three vibration modes.

2. Basic Construction of Stator Vibrator

For strong excitation, there are two concepts of the excitation of the stator by MPAs and the increase the rigidity of the friction driving unit of the stator. The MPA which utilizes a piezoelectric longitudinal effect with high electromechanical coupling coefficient, kvn can obtain a large displacement and large generated force. It was confirmed that the kvn of the bending vibration mode excited by MPA was approximately twice larger than that of the excitation by an adhered piezoceramic plate. In addition, low-voltage driving can be realized by the multilayer effect of MPA. The stator has a high rigidity by increasing the thickness of the contact portion with the rotor. Furthermore MPA is arranged embedded in the inner and outer surfaces of the stator vibrator. Thus, it is possible to suppress the attenuation of the excited vibration force and increase the driving force to the rotor. The designed stator is shown in **Fig.1**.



(a) Appearance.　　(b) Cross section at A-A'.
Fig.1 Stator construction. (Material:SUS304)

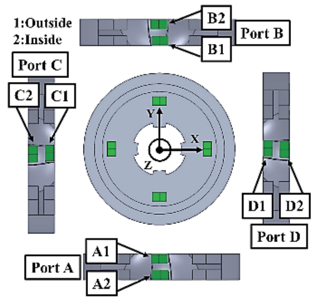


Fig.2 MPA arrangement.

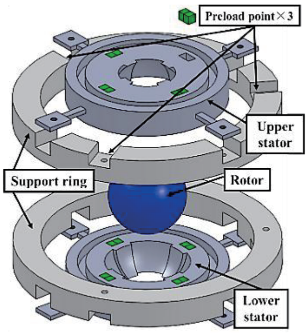


Fig.3 Component parts of sandwich structure.

3. Operating Principle

The MDOF-SUSM using annular stator vibrator can excite three kinds of vibrational modes: radial vibration mode(R_1-mode), bending vibration mode(B_{21}-mode), and nonaxisymmetric vibration mode(((1,1))-mode) independently. In addition, their orthogonal vibrational modes, B_{21}'-mode, ((1,1))'-mode can also be excited. A spherical rotor can rotate around three axes by combining the different vibration modes[2)]. The MPA arrangement of designed stator is shown in **Fig.2**. **Table I** and **Ⅱ** show excitation methods concerning the phase difference of each port and combination of each electrical port, respectively.

Table I Excitation method of each vibration mode.

Phase difference [deg]		Vibration mode
①	②	
0	0	R_1-mode
180	180	B_{21}-mode
180	0	((1,1))-mode

※①MPA pair on the opposite side(Port A-B or Port A-D)
②MPA pair on the inside and outside (1-2 in each Port)

Table II Operating method of each rotation.

Vibration mode		Rotation direction
Port A-B	Port C-D	
R_1-mode	B_{21}-mode	X-axis
B_{21}'-mode	R_1-mode	Y-axis
((1,1))-mode	((1,1))'-mode	Z-axis

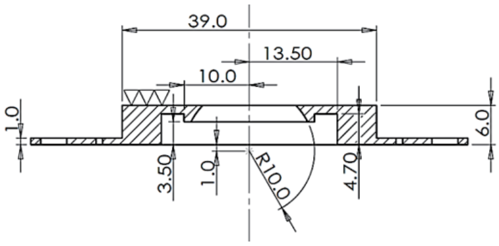
4. Basic Structure of Motor

The basic construction of this type of an MDOF-SUSM is shown in **Fig. 3**. The stator is fixed to the support ring at four points. The support ring is used for pre-load adjustment. This construction improves the stability and make any uniform preload by three points. The support ring should not give a bad effect on the vibration mode. Therefore the adjustment of the shape and dimensions was carried out by finite element analysis(FEA). Moreover, it was designed to approximate the resonance frequency of the R_1-mode and B_{21}-mode. Simulated results of resonance frequencies of the stator are: B_{21}-mode is 21.32kHz, R_1-mode, 21.41kHz, ((1,1))–mode, 24.30kHz.

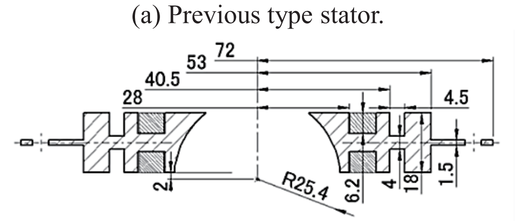
5. Comparison between Prototype and Previous type

5.1. Stator Dimension

The stator of the prototype MDOF-SUSM utilized MPAs as the source of excitation. The MPAs were embedded into rectangular hole which is formed on the stator, and they were adhered with a metal wedge for fit into the hole. A cross-sectional view with the scale of the stator is shown in **Fig. 4** to compare the prototype stator with previous one[2]. For the generation of high torque, the prototype stator is designed for the spherical rotor 2.5 times larger than that of previous type. Therefore, the main part of the prototype stator is about 2.7 times larger than that of previous type. Each vibration mode in the previous type is excited by the piezoceramic disc adhered on the surface of the stator.



(a) Previous type stator.



(b) Prototype stator.

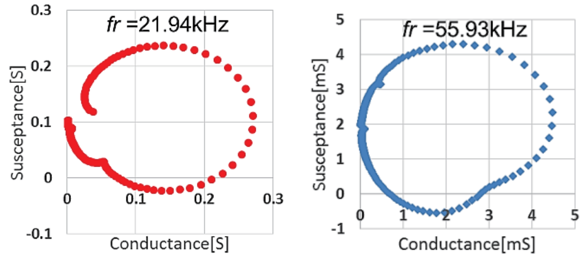
Fig.4 Cross section of stators. (Unit: mm)

5.2. Admittance Characteristics

The measured admittance loops of B_{21}-mode of the prototype and the previous type of are shown in **Fig. 5**. The dynamic admittance in the prototype was 0.27 S. This value is about 60 times larger than that of the previous type. In addition, the resonance quality factor of 426 was obtained. This value is about 2.2 times as large as that of the previous type.

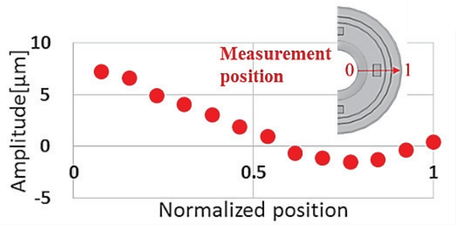
5.3. Vibration Displacement

Figure 6 shows the vibration displacement measured by a laser Doppler vibrometer on the upper surface of the stator when the B_{21}-mode was excited. The vibration amplitude of 7.27μm was obtained near the inner diameter of the contact portion with the rotor on the prototype stator. This value is about 48.5 times larger than the vibration amplitude, 0.15μm, of the previous type. Strong excitations were obtained in other vibration modes as well.

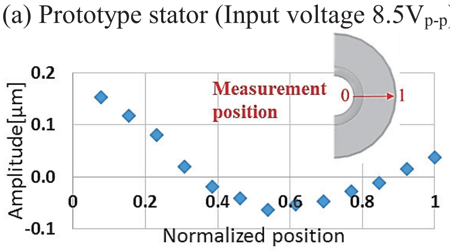


(a) Prototype stator (b) Conventional stator

Fig.5 Measured admittance loop of B_{21}-mode



(a) Prototype stator (Input voltage 8.5V_{p-p})



(b) Conventional stator (Input voltage 8.5V_{p-p})

Fig.6 Measured vibration amplitude of B_{21}-mode

6. Conclusion

The stator using the annular vibrator which can strongly excite three types of vibrational modes by using MPA was realized. The comparison between the prototype and the previous type was carried out by measuring the admittance characteristics and vibration displacement. As a result, it was confirmed that the prototype excited stronger than the previous type. Hereafter, to confirm the effect of the strong excitation configuration, it is necessary to evaluate the performance of torque.

Acknowledgment

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