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Examination of Sandwich-type Multi-degree-of-freedom Spherical Ultrasonic Motor
サンドウィッチ型多自由度球面超音波モータの検討

Bo Lu[1†], Manabu Aoyagi[1], Takehiro Takano[2] and Hideki Tamura[3] ([1]Gradu. School Eng., Muroran Inst. of Tech.; [2]Facult. Eng., Tohoku. Inst. of Tech., [3]Gradu. School Sci. and Eng., Yamagata Univ.)
盧波 [1‡], 青柳学 [1], 高野剛浩 [2], 田村英樹 [3] ([1]室蘭工大 院工; [2]東北工大 工, [3]山形大 院理工)

1. Introduction

In recent years, the research field of a humanoid and bionic robots has been developing, so that an actuator system with multi-degree-of-Freedom(MDOF) of motion and complicated action was aspired to research and develop. If the MDOF motion is realizable using only a single actuator device, the downsizing of systems and the simplicity of designs can be achieved effectively. Some research results concerning a MDOF spherical ultrasonic motor(SUSM) have been reported before[1-4]. The authors also have developed the MDOF SUSM whose stator vibrator using an annular plate which can excite multiple vibration modes[5]. The purpose of this research is to increase the torque of MDOF SUSM using annular stator vibrator and to downsize it.

In this paper, a sandwich structure in which the spherical rotor is held and combined between two stator vibrators is proposed. Each stator vibrator can be excited five vibration modes. A new sandwich-type MDOF SUSM is redesigned and developed to obtain advanced performance.

2. Operating Principle

The operating principle of the sandwich-type MDOF SUSM is shown in **Fig. 1**. Five vibration modes can be excited independently and simultaneously by a single stator vibrator. A spherical rotor can rotate round three axes by combining the different vibration modes. **Table I** is an introduction to the driving ways.

Table I Combination of vibration modes.

Drive frequency	Frequency f_1		Frequency f_2
	X-axis	Y-axis	Z-axis
Electrode A	①	②	④+⑤
Electrode B	①	②	④+⑤
Electrode C	③	③	—
Vibration mode	①B_{21}-mode;②B_{21}'-mode;③R_1-mode;④((1,1))-mode;⑤((1,1))'-mode;		

E-mail address: s1971008@mmm.muroran-it.ac.jp

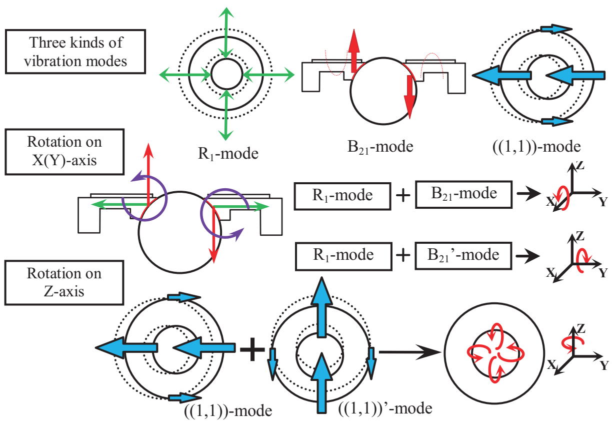

Fig. 1 Operating principle of MDOF SUSM.

3. Basic Construction

1. The stator of the MDOF SUSM and an electrode pattern on the piezoceramic plate 0.5mm thick which is adherent on the outside of the stator are shown in **Figs. 2(a)** and **(b)**, respectively. In the cause of obtaining a large torque, the spherical surface is formed on the contact surface between the rotor and the stator[6]. The electrode of the piezoceramic plate exciting a variety of vibration modes are cut into five parts. In accordance with the distribution of the piezoceramic plate, the stator can excite three kinds of vibration modes; a bending vibration mode(B_{21}-mode), a radial vibration mode(R_1-mode) and a nonaxisymmetric vibration mode(((1,1))-mode). Analytical results about the stator by a multipurpose finite element method analysis are: B_{21}-mode is 57.77kHz, R_1-mode, 57.89kHz, ((1,1))–mode, 66.03kHz.

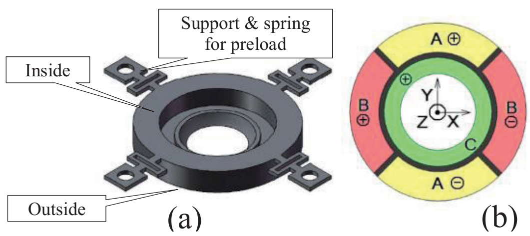

Fig. 2(a) Construction of the stator, and (b) arrangement of electrodes of piezoelectric ceramic ring.

2. The basic construction of this SUSM is shown in **Fig. 3**. A spherical rotor is held between two stators having a simple structure. Moreover, the construction of the supporting parts of the stator is

simply designed for a miniaturization.

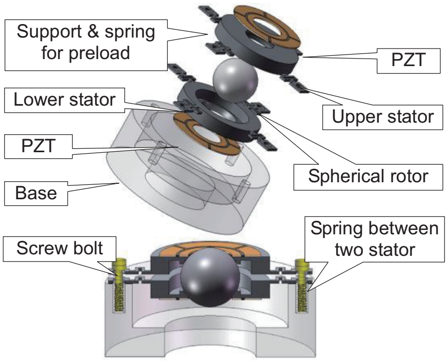

Fig. 3 Component parts of sandwich structure.

4. Measurement results

1. Four screws and four springs built in the stator, which make a uniform preload on the rotor. Meanwhile, coil springs on the contact part between the screws and support parts of the stator can reduce adverse vibrations which occur on them. As a result, the motor gained a more stable performance. Three types of arrangement of springs and screws were examined:

a. Preload by the tightening of just four screws (usage of own elastic feature of the support part).

b. Preload by the downward pressure of the coil springs lying between upper stator and the screws.

c. Preload by the combination of the screws and the coil spring set between two stators.

Figure 4 shows the relations between torque and applied voltage in the X(Y) axis rotation and the same voltage was applied to excite B_{21} (B_{21}')-mode and R_1-mode. The preload method c stabilized a motor operation, and adverse vibrations were minimized. The same result was obtained about Z-axis rotation.

2. **Table II** exhibits the comparison results of the former form and the present one. We can get a conclusion that the motor in this study achieved downsizing and increase of torque were confirmed.

Table II Comparison between present and former SUSM.

MDOF-USM type		Present	Former
Diameter [mm]	Stator	39.0	67.2
	Rotor	20.0	25.4
Max torque [mNm] (V_{p-p})	X(Y)	58.04(80)	93.3(120)
	Z	84.5(140)	67.8(220)

3. The present SUSM has a spherical contact surface and it achieves the desired purpose of miniaturization and increase of torque. In order to investigate and confirm whether the spherical contact surface is an important factor which results in the achievement of large torque, an SUSM with a conical contact surface in the same size was manufactured as a trial. The measurement results of both motors with the preload method c are illustrated in **Fig. 5**. According to this, it was confirmed that the spherical contact surface was an important factor for increasing torque.

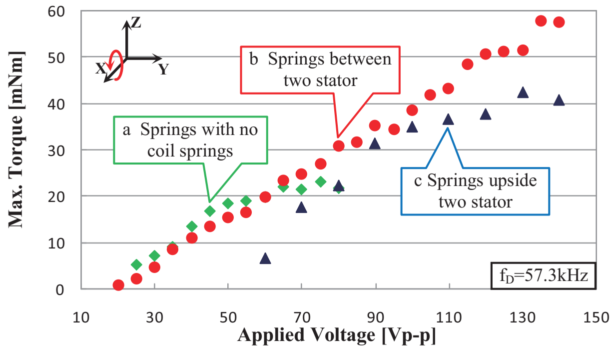

Fig.4 Max.torque & applied voltage on X(Y)-axis.

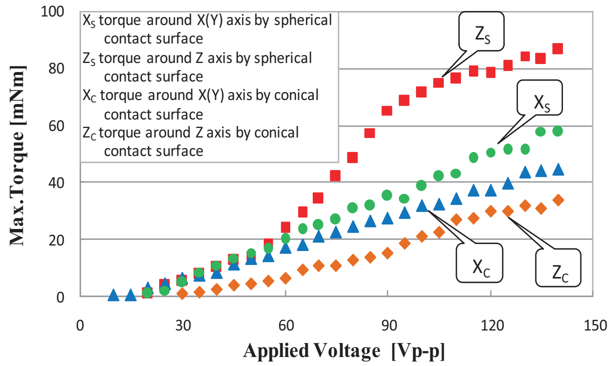

Fig.5 Max.torque & applied voltage between motors with spherical contact surface and conical one.

5. Conclusions

In this study, a sandwich-type MDOF SUSM for realizing miniaturization and a high torque performance was experimentally considered. Moreover, the displacement magnification mechanism, which was used in the former SUSM form, to rotate the spherical rotor on the Z axis is no longer necessary. Hence the design of the motor has become simple. It is confirmed that the spherical contact surface is an important factor which results in the achievement of large torque has been confirmed. Further research will be put on the realization of higher performance.

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