Development of Spherical Ultrasonic Motor for Critical Environment

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Abstract. In recent years, due to advances in science technology, space satellites have made progress. So, the presence of space debris has become problem in the world because they may collide each other. In our study, we have developed Spherical Ultrasonic Motor (SUSM) for space use with 3 DOF to drive the satellite thruster and resolve it. We aim that the satellites enter the atmosphere when the satellites reached the end of life, and SUSM controls thrusters when they inject for the directional control. We have made experiments of measuring torque, durability and lifetime. It shows that the torque and lifetime meets target value. But durability does not meet target value. To resolve it, we have applied stator lining materials and shifted frequency with 0.4kHz from resonant frequency and we have shown that it meets durability-required specifications.

1. Introduction

Recent many countries launched a lot of space satellites. So, space debris has become a problem in the world. It is because the space debris cause to collide satellites. In our research, we apply our 3DOF Spherical Ultrasonic Motor (3DOF SUSM) to resolve this problem. For the use of our motor in outer space, it is necessary to meet space use specifications. Such as required output torque and durability in the high vacuum. Especially heat is serious problem. By reducing generated heat of the motor by lining material and resonance frequency shift, we are able to rotate the motor under high vacuum environment for 120 minutes. The specifications of the motor in space is as follows; maximum output torque 25mNm, continuous working time 120 minutes, cycles of working more than 300 times.

2. Spherical ultrasonic motor

The 3DOF SUSM used in this study consists of one spherical rotor and three ring-shaped stators. Figure 1 shows an overview of the 3DOF SUSM. The geometric schemes are illustrated in Figure 2. The stator includes a metallic elastic body and piezoelectric elements. When an AC voltage is applied to the piezoelectric vibrator, a standing wave is generated on the elastic body. By applying two AC voltages with a phase difference to the positive and negative sections of the piezoelectric elements, a traveling wave is generated due to combination of the two standing waves. The stators and the rotor are in pressure contact with each other, and the rotor is driven by the tangential force of the elliptical motion of the traveling wave [1-2].

2.1. Basic experiments

We have experiments of SUSM in the vacuum chamber (applied voltage 180Vpp, applied resonant frequency, air pressure10^{-3}Pa) to measure output torque and rotational speed.

2.2. Rotational velocity and output torque

An experimental apparatus is shown is Figure 3. We have applied phase difference 0 degree, 60 degree, and -60 degree to stators to rotate about *Y*-axis and measured its rotational velocity and output torque. The results are shown in Table 1 and Figure 4. They show that working time is only 4 minutes in the vacuum environment and maximum speed is degenerated 17 percent comparing to the case in

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air. But the output torque increased 20 percent. It is because that some materials on the surface of the rotor and stator are vapored out and the frictional force increased.

3. Lining material and resonant frequency

Based on the above results, we have improved the motor for use of space. Firstly, we have applied the new lining material on the surface of rotor as follows; #1A (Molybdenum disulfide), FS-1140 (Fluorine resin), #815-4 (Fluorine resin), S-6100 (Fluoridation graphite). These materials have good characteristics in space such as low wear, high frictional force and high durability under high temperature. The experimental results are shown in Figure 5, Table 2 and 3. All motors generated higher output torque than required specifications. However working time is much less than required specifications (120 minutes). It is because that generated heat changes the resonant frequency and stator cannot vibrate nor drive the rotor.

In order to make working time longer, we have applied near resonant frequency (0.4kHz higher shift) to the stators so that it may make the vibration amplitude smaller to resolve frictional heat. The results are shown in Figure 6 and 7 and Table 4. We have found that it meets the specifications of torque and working time.

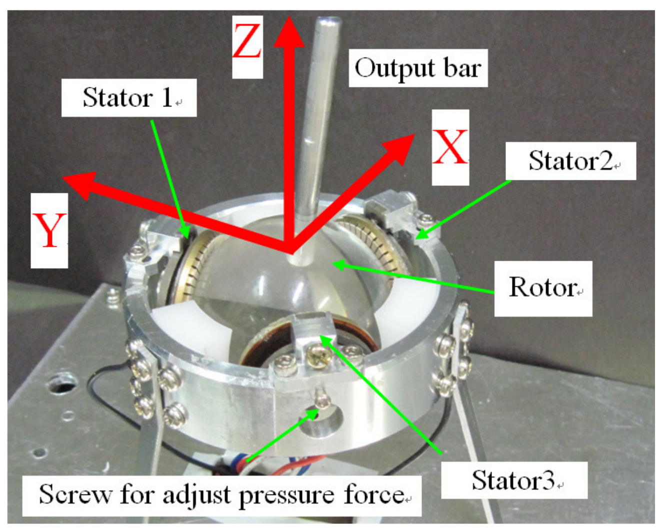
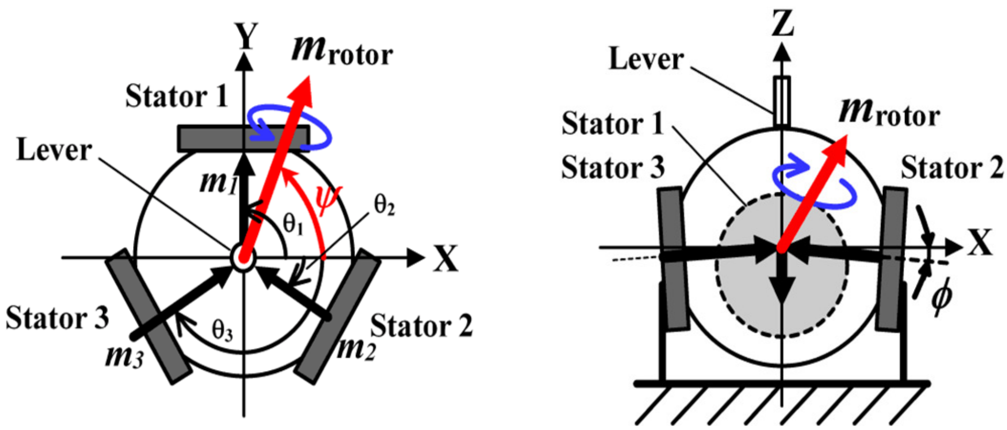


Figure 1. 3 DOF spherical ultrasonic motor.



a) Geometry from top view b) Geometry from top view

Figure 2. Geometric schemes of 3DOF SUSM.

Table 1. Experimental results of rotational speed and torque in high vacuum.

Atmosphere	High vacuum	Atmosphere
Rotational speed [rpm]	74.2	64.1
Torque [mNm]	29.3	35.3

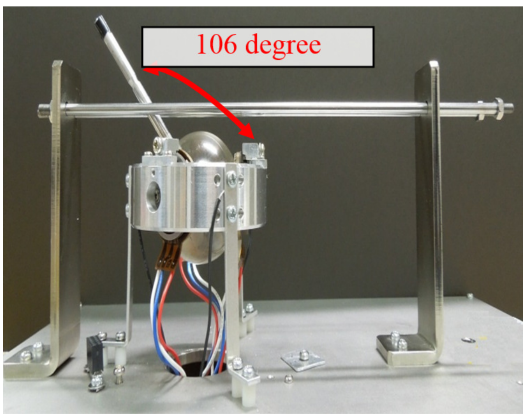


Figure 3. Experiment equipment for measuring rotational speed.

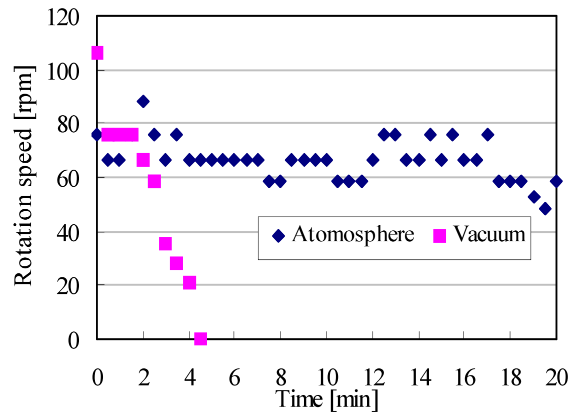


Figure 4. Result of durability experiment in the atmosphere vs in vacuum.

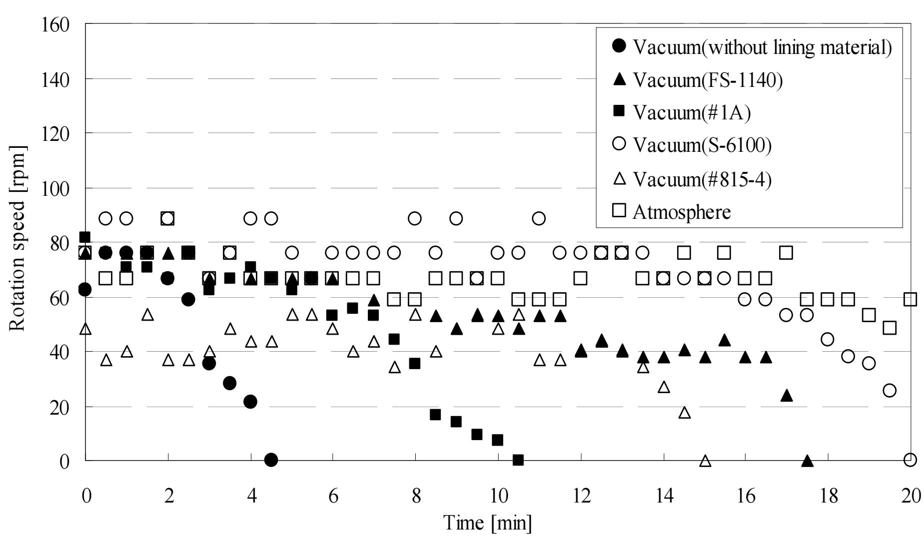


Figure 5. Durability of motor with lining materials.

Table 2. Rotation speed in vacuum each lining materials [rpm].

FS-1140	75.7
#1A	81.5
S-6100	75.7
#815-4	48.2

Table 3. Torque in vacuum each lining materials [mNm].

	Atmosphere	Vacuum(estimate)
FS1140	28.0	33.7
#1A	27.8	33.5
S-6100	21.4	25.8
#815-4	21.2	25.5

Table 4. Lifetime of SUSM.

Atmosphere	327
Vacuum	758

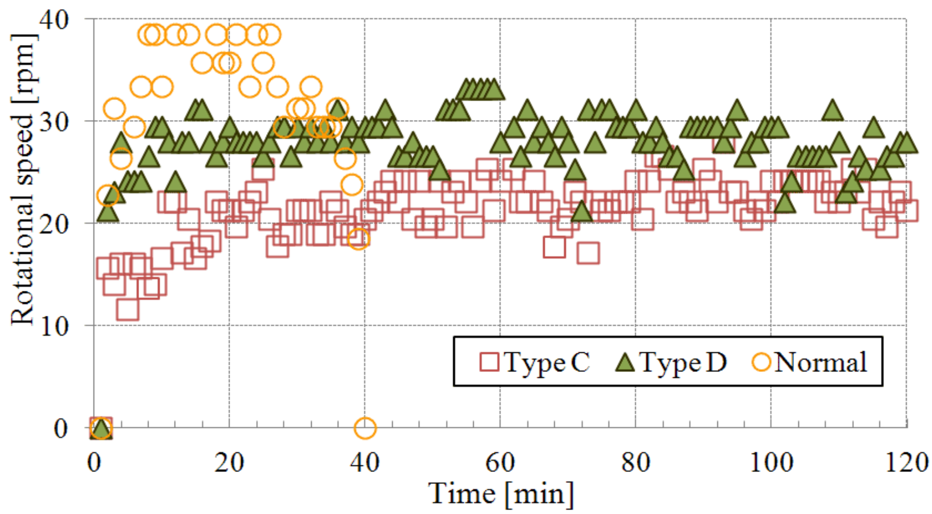


Figure 6. Durability experiment.
Type C (S-6100), Type D (Fs-1140), Normal (no lining material)

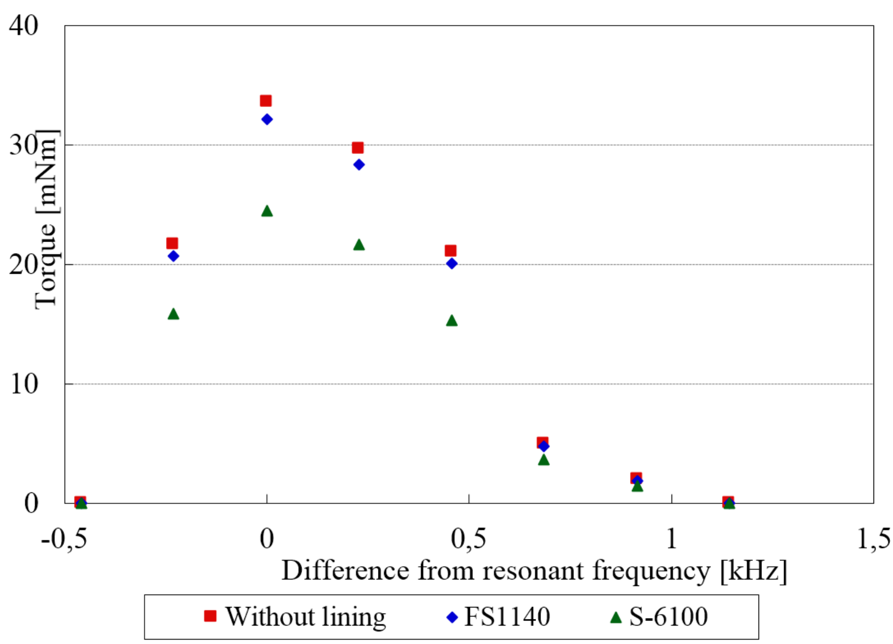


Figure 7. Relationship between frequency and torque.

4. Conclusions

We have developed a new spherical ultrasonic motor for space use. Applying new lining materials and resonant frequency shift to the stators, it meets the space specifications, that is, maximum output torque 25mNm, continuous working time 120min., cycles of working more than 300 times. We have succeeded in showing its potentials for use in space.

References

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