

Micro spherical ultrasonic motor using single spiral wire stators

Fulin Wang¹, Uichi Nishizawa², Shigeki Toyama³

¹Nanjing PANDA Electronics Co., Ltd., Nanjing, China

^{1, 2, 3}Tokyo University of Agriculture and Technology, Tokyo, Japan

¹Corresponding author

E-mail: ¹zjwangfulin@163.com, ²n-uichi@cc.tuat.ac.jp, ³toyama@cc.tuat.ac.jp

Received 3 August 2017; accepted 4 August 2017

DOI <https://doi.org/10.21595/vp.2017.18942>



Abstract. The authors have developed Multi degree-of-freedom micro spherical ultrasonic motor using multiple spiral wire stators in previous research. In this research, the authors have developed the new spherical ultrasonic motor using single spiral wire stators. At the beginning, single spiral type wire stator was made. Next, rotational direction was controlled by duty ratio of traveling wave and standing wave. Then the drive properties of rotational speed and starting torque were clarified in this research. In the future, fixing method of wire stators without damping the vibration is needed to be planned. These results contribute to development of blood vessel endoscope which can move camera in any direction.

Keywords: spherical ultrasonic motor, spherical rotor, wire stator, angioscopy.

1. Introduction

There are various inspection methods such as using angioscopy in the diagnosis of vascular disease, but the angioscopy is difficult to observe a precise image in the blood vessel from the front. To solve this problem, the authors have been developing blood vessel endoscope with a micro spherical ultrasonic motor which can move camera in any direction.

The imaginal diagram of micro spherical ultrasonic motor is shown in Fig. 1. The schematic diagram of micro ultrasonic motor is shown in Fig. 2. When vibration is applied at waveguide of wire stators, traveling wave is generated and spherical rotor is driven.

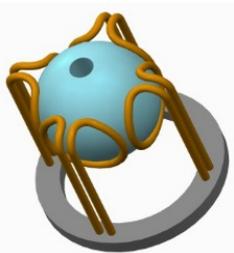


Fig. 1. Imaginal diagram of micro spherical ultrasonic motor

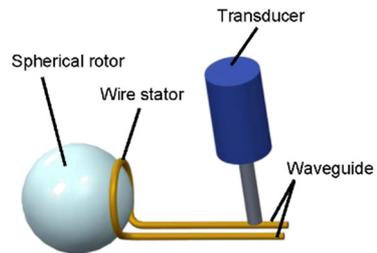


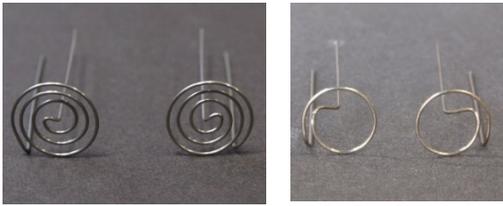
Fig. 2. Schematic diagram of micro ultrasonic motor

2. Single spiral type of wire stator spherical ultrasonic motor

The authors have made spiral wire stators as shown in Fig. 3. The authors have made two kinds of wire stators; single and multiple spiral wire stators. The specification of each stator is shown in Table 1. In the previous research, the authors have used multiple spiral wire stators with a pair of right and left spiral ones because of torque's first priority. However, the contact area between the multiple spiral wire stators and the spherical rotor is small and irregular because of machining error. Therefore, the authors have used single spiral wire stators due to the stable rotation. In order to prevent mutual contact between the two stators for 2-axis drive, the outside diameter of spiral is 10.0 mm.

The authors have made two degree-of-freedom spherical ultrasonic motor using single spiral

wire stators as shown in Fig. 4. It has two sets of wire stators orthogonal each other. It is controlled by applied voltage.



a) Multiple spiral b) Single spiral
Fig. 3. Wire stators

Table 1. Specification of each stator

Number of spirals	3	1
Outside diameter of spiral [mm]	12	10
Length of wave guide [mm]	30	
Wire diameter [mm]	0.5	
Material	SUS304	

There are two ways of traveling wave direction; traveling from outside to the center and traveling from the center to outside. In this paper, the authors call the former way a forward driving and the latter way a reverse driving. The forward driving and reverse driving are shown in Fig. 5. In previous research, it has eight rotational direction as shown in Fig. 6 and Table 2.

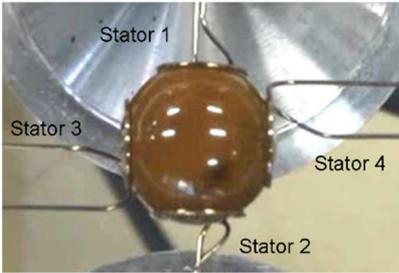
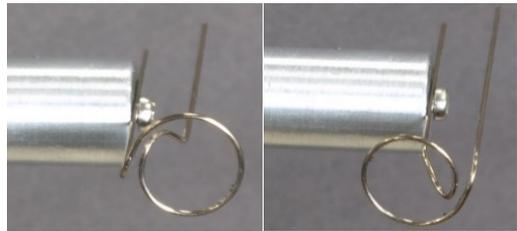


Fig. 4. Experiment equipment for 2-axis drive



a) Forward b) Reverse
Fig. 5. Connection method

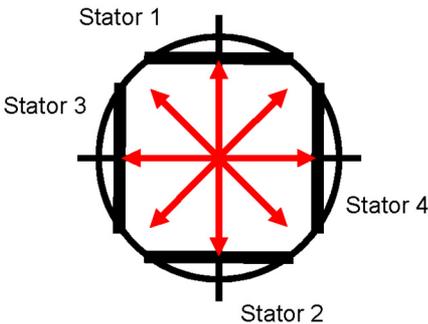


Fig. 6. Rotational direction

Table 2. Relationship between rotational direction and output of each stator

Direction	Stator 1 & 2	Stator 3 & 4
Right	Forward	Standing wave
Upper Right	Forward	Forward
Upper	Standing wave	Forward
Upper Left	Reverse	Forward
Left	Reverse	Standing wave
Lower Left	Reverse	Reverse
Lower	Standing wave	Reverse
Lower Right	Forward	Reverse

3. Precise control of rotational direction of wire stator spherical ultrasonic motor

In this research, rotational direction can be precisely controlled by duty ratio of traveling wave and standing wave.

The experimental equipment of duty ratio is shown in Fig. 7. In the experiment, the authors have put a black mark on the spherical rotor using for showing the rotational direction. Six Langevin transducers are connected with four wire stators. Langevin transducers A, C, E, and F are connected to the forward driving. Langevin transducers B&D are connected to the reverse driving. The wave of each stator is shown in Fig. 8. The period of output of Langevin transducers B&D are 0.01 s, the duty of output is from 0 % to 100 %. When Langevin transducers B&D are turned OFF and Langevin transducers A, C, E, and F are turned ON, all stators generate traveling wave, the direction of the spherical rotor is upper right. When Langevin transducers B&D are

turned ON, the combination of traveling wave of stators A&B and the traveling wave of stators C&D are standing wave, but stators E&F generate the traveling wave, the direction of the spherical rotor is right. When the output of Langevin transducers B&D are duty ratio, the direction of the spherical rotor is between the two directions as shown in Fig. 7. The rotational direction can be precisely controlled by duty ratio.

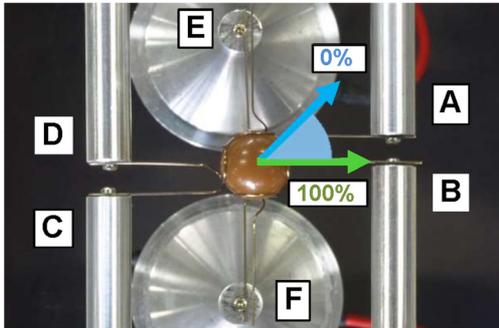


Fig. 7. Experimental equipment of duty ratio

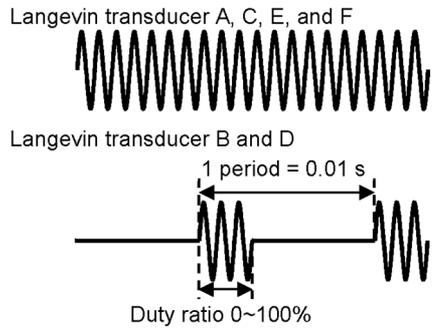


Fig. 8. Wave of each stator

The experimental conditions are as following. The duty ratio is changed by 10 %. The applied voltage is 20 V_{p-p}. The applied frequency is 24.6 kHz. The defined angle of the rotational direction is shown in Fig. 10. The relationship between angle of rotational direction and duty ratio is shown in Fig. 9. The angle of rotational direction decreases with increasing the duty ratio. From the experimental results, the influence of the driving force is small, but the rotational direction can be controlled by duty ratio.

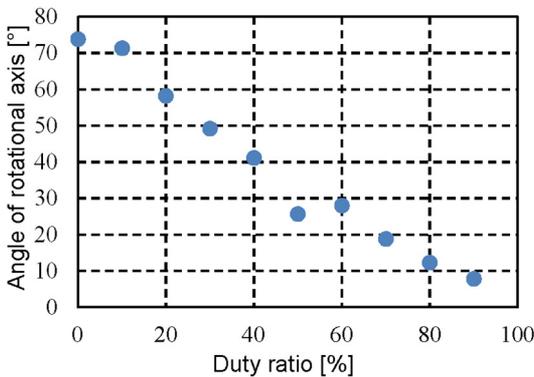


Fig. 9. Relationship between angle of rotational direction and duty ratio

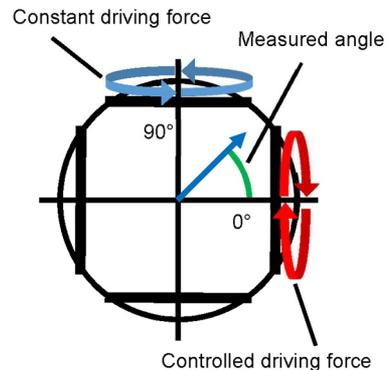


Fig. 10. Rotational axis and measured angle

4. Performance evaluation of wire stator spherical ultrasonic motor

4.1. Relationship between pressing force and rotational speed

The experimental equipment of pressing force is 1-axis driving as shown in Fig. 11. The spherical rotor of diameter 15 mm is located in two wire stators. The experimental conditions are as following. Step 1, the applied frequency is 24.6 kHz, the applied voltage is 10 V_{p-p}. Step 2, one wire stator is pushed to move in the direction of the arrow as shown in Fig. 11, the contact point between the spherical rotor and wire stator is 0 mm as the reference point, one stator is moved from 2 mm to 4 mm by 0.1 mm, another stator is fixed and pressed, the rotational speed is measured. Step 3, the applied voltage is changed from 10 V_{p-p} to 70 V_{p-p} by 10 V_{p-p}, then step 2 is repeated. The pressing force is obtained from the load cell in the experiments.

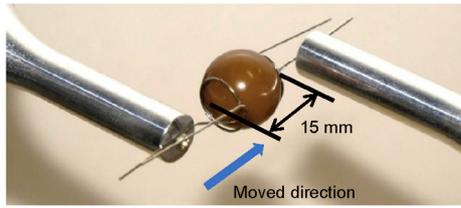


Fig. 11. Experimental equipment of pressing force

The experimental results are shown in Fig. 12 and Fig. 13.

The relationship between pressing force and rotational speed with the applied voltage changed from $10 V_{p-p}$ to $30 V_{p-p}$ is shown in Fig. 12. The rotational speed is tended to decrease as the pressing force increases and the change is small after pressing force 0.8 N. In addition, the rotational speed is increased a little before and after 0.8 N. As a cause, the wire stators are deformed as the pressing force increases, the contact position of the spherical rotor and wire stator can be shifted slightly, the direction of vibration transmission is changed.

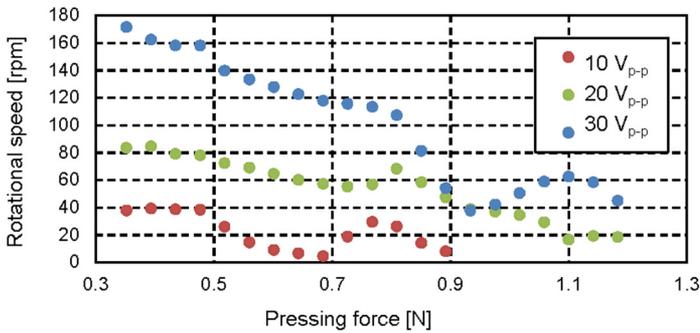


Fig. 12. Relationship between pressing force and rotational speed ($10 V_{p-p}$ - $30 V_{p-p}$)

The relationship between pressing force and rotational speed with the applied voltage changed from $40 V_{p-p}$ to $70 V_{p-p}$ is shown in Fig. 13. The rotational speed is decreased in the vicinity of pressing force 0.4 N. The rotational speed is increased as the pressing force is changed from 0.5 N to 0.7 N, the rotational speed is maximum in the vicinity of 0.7 N. In addition, the relationship between amplitude of voltage and pressing force is shown. The rotational speed is increased as the amplitude of voltage decreases before 0.5 N. The relationship between rotational speed and amplitude of voltage is reversed as the pressing force is changed from 0.5 N to 0.7 N. As a cause, the vibration in the contact area between the wire stators and the spherical rotor is large in the condition of weak pressing force and high voltage. Therefore, ultrasonic vibration is considered suitable for transmission to the spherical rotor.

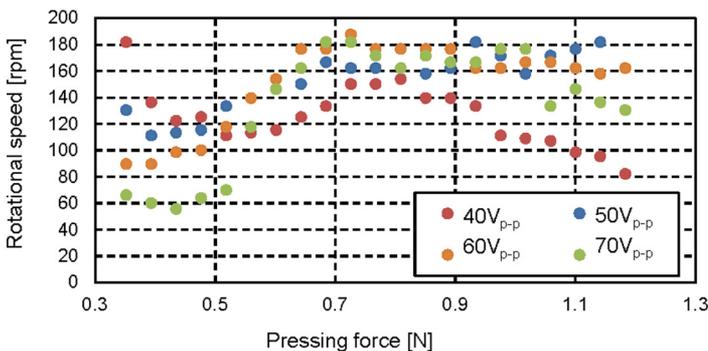


Fig. 13. Relationship between pressing force and rotational speed ($40 V_{p-p}$ - $70 V_{p-p}$)

4.2. Experiment of starting torque of wire stator spherical ultrasonic motor

The experimental equipment of starting torque is 1-axis driving with a string as shown in Fig. 14. The spherical rotor of diameter 15 mm is located in two wire stators.

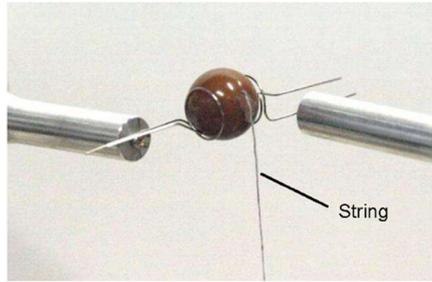


Fig. 14. Experimental equipment of starting torque

First, the applied voltage is fixed to $40 V_{p-p}$, the starting torque is measured by changing the applied frequency. The weights are attached in the end of string, the vibration is generated to the wire stators, the spherical rotor is driven, and the operation of the spherical rotor is observed. The spherical rotor is stopped when the weights are 1000 mg. The load is reduced by 10 mg until the spherical rotor start to rotate. The above operation is repeated from the applied frequency changed by 0.005 kHz. The starting torque is maximum at frequency 24.6 kHz. The relationship between frequency and starting torque of forward rotation is shown in Fig. 15. The relationship between frequency and starting torque of reverse rotation is shown in Fig. 16.

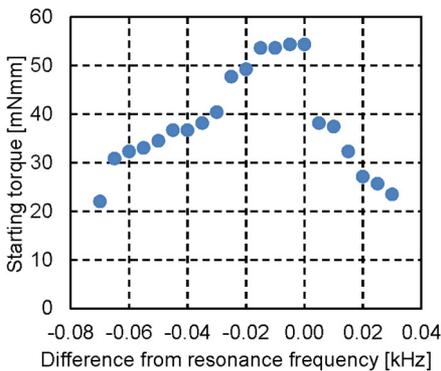


Fig. 15. Relationship between frequency and starting torque of forward rotation

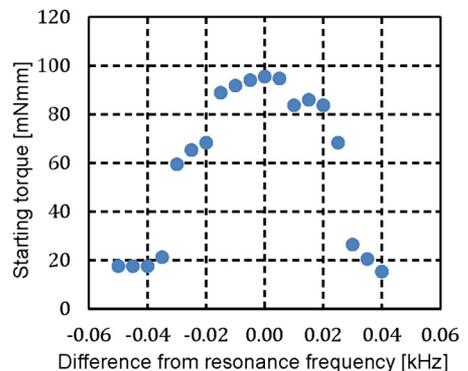


Fig. 16. Relationship between frequency and starting torque of reverse rotation

Second, the frequency is fixed to 24.6 kHz, the applied voltage is changed from $10 V_{p-p}$ to $70 V_{p-p}$, and the starting torque is measured. The relationship between amplitude of voltage and starting torque of forward rotation is shown in Fig. 17. The relationship between amplitude of voltage and starting torque of reverse rotation is shown in Fig. 18.

The starting torque is high when the applied voltage is low. The starting torque is decreased rapidly in the vicinity of voltage $20 V_{p-p}$ of forward rotation and $30 V_{p-p}$ of reverse rotation. The cause of the phenomenon is the friction. The vibration in the contact surface of the wire stator is small at low voltage. Therefore, the static friction between the spherical rotor and wire stator is considered to cause high starting torque. The vibration in the contact area between the wire stators and the spherical rotor is large and the pressing force is low at high voltage. Therefore, the dynamic friction between the spherical rotor and wire stator is considered to cause low starting torque. The friction is changed from static friction to dynamic friction as the applied voltage

increases, the driving force to the spherical rotor is reduced and the starting torque is reduced.

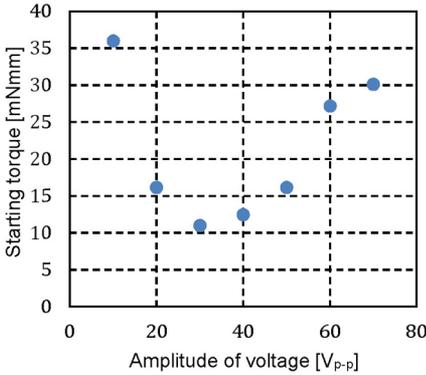


Fig. 17. Relationship between amplitude of voltage and starting torque of forward rotation

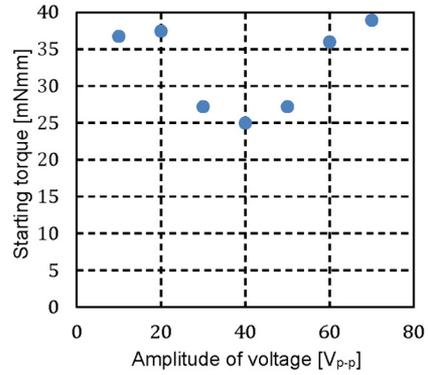


Fig. 18. Relationship between amplitude of voltage and starting torque of reverse rotation

5. Conclusions

In this research, the authors have concluded as follows:

1. The authors have designed and made an ultrasonic motor using single spiral wire stators.
2. The authors have examined that the rotational direction can be controlled by duty ratio.
3. The authors have showed the drive properties of rotational speed and relationship between amplitude of voltage or frequency and starting torque.

References

- [1] **Takesue N., et al.** Position control methods of spherical ultrasonic motor. Proceedings of IEEE/RSJ International Conference on Intelligent Robots and Systems, 2010, p. 3061-3066.
- [2] **Sashida T., Kenjo T.** An Introduction to Ultrasonic Motors. Oxford University Press, Oxford, 1993.
- [3] **Purwanto E., Toyama S.** Control method of a spherical ultrasonic motor. Proceedings of IEEE/ASME International Conference on Advanced Intelligent Mechatronics, 2003, p. 1321-1326.
- [4] **Mashimo T., Awaga K., Toyama S.** Development of a spherical ultrasonic motor with an attitude sensing system using optical fibers. Proceedings of IEEE international conference on robotics and automation, 2007, p. 4466-4471.