Development of IVUS (Intravascular Ultrasound) Driven by Ultrasonic Micromotor
-Principle of Drive and Detection Methods-

Tetsuro WADA[1], Akihei NAKAJIMA[1], Tadashi MORIYA[2] and Yuji FURUKAWA[3]
[1]Department of Mechanical Systems Engineering, Tokyo University of Agriculture and Technology, [2]Department of Electrical Engineering, Tokyo Metropolitan University, [3]Professional Graduate School, Management of Technology, Tokyo University of Agriculture and Technology

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Abstract

In this paper, we try to develop a miniaturized ultrasonic angina-pectoris scope, namely, miniaturized IVUS which is rotated by another ultrasonic micro motor for the observation of cerebral thromboses in brain vessels. As a first step of research, a prototype of IVUS with 3 mm outer diameter and 10 mm length has been developed and its torque-rotational speed characteristic was examined. And the principle to detect cerebral thromboses by sending ultrasonic sound to the radius direction of a blood vessel and catching its reflection while it is rotated by a micro motor was proposed and its fundamental characteristics were verified.

1 Introduction

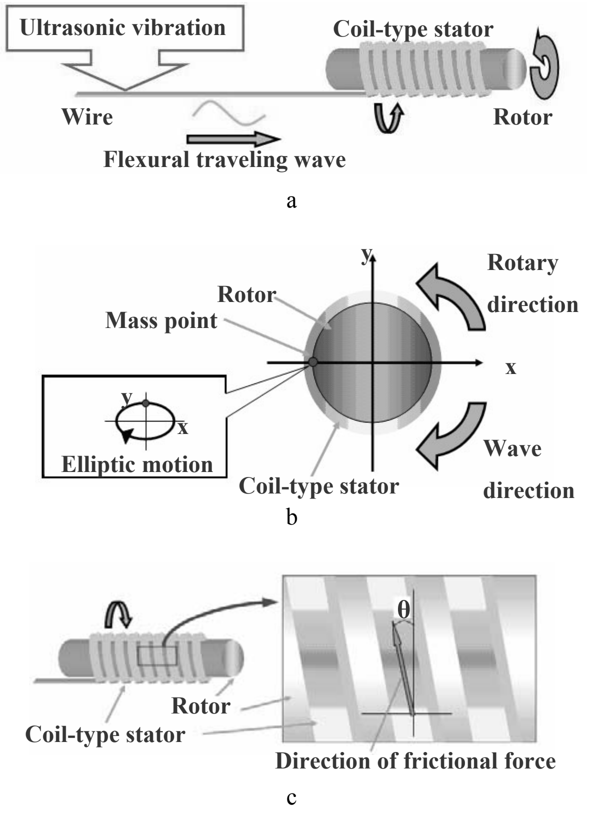
As it is desired to operate human bodies without having to cut them open, operations guided by a catheter are widely carried out today for heart and blood vessel diseases. Although ultrasonic angina-pectoris scopes are widely used for the internal observation of blood vessels, it is difficult to apply them for the observation and removal of cerebral thromboses in brain vessels, because their small diameter of less than 2 mm makes it difficult to insert and rotate devices attached at the end of a catheter.

To overcome this problem, in this present study, we tried to develop a miniaturized IVUS which can be rotated by another ultrasonic micromotor. Ultrasonic micromotor is rather easy to miniaturize because of its simple structure, hence, it is expected to be applied in many industries, and outstandingly as a driver of medical devices that operates inside a human body[1] [2].

In this report, driving principle and a performance evaluation of a prototype of a ultrasonic micromotor which is applied to a miniaturized IVUS, and the principle and a fundamental experiment of the method of internal observation in a blood vessel by the reception and transmission of the ultrasonic vibration are described.

2 Driving principle of ultrasonic micromotor

Fig. 1 a shows the schematic diagram of the ultrasonic micromotor. The prototype micromotor consists of an external vibrator, a waveguide, a stator and a rotor. The thin wire made of SUS receives ultrasonic vibration from the vibrator that is attached to one end of the waveguide (hereinafter, the waveguide is described as the arm part of the coil) and propagates it to a helical coil (stator).



a

b

c

Fig. 1. Driving principle of ultrasonic micromotor

The progressive flexural wave in the helical coil generates micro frictional force at the contact points between the rotor and the coil and the sum of these microfrictions can produce an elliptical motion to rotate the rotor as shown in Fig. 1 b. During this time, the frictional force works oppositely to the forward direction of the progressive wave.

Moreover, the frictional force is not only influenced by the direction of the rotation but also by the axial derection of the rotor because the progressive wave progresses along the spiral structure of the coil (as shown in Fig. 1 c). Therefore, the rotor perfoms a rotary motion and a translational motion. In the case shown in Fig. 1, the rotor is placed inside the coil, but an opposite location is also possible.

3 Prototype of ultrasonic micromotor

A prototype of ultrasonic micromotor with 3 mm outer diameter and 10 mm length has been developed (Fig. 2). It consists of a rotor, a coil, a case, and a stopper. The arm part of the coil has 1.5 m length. The coil is placed around in the rotor and the outer diameter of the coil fits the inner diameter of the rotor. The rotor is covered with the case and the rotor is supported anteroposteriorly and radially by fitting one end of the case with the stopper. The material for the rotor and coil is SUS301 which has a good biocompatibility and that for the case is a TI polymer which has a heat resistance and an abrasion resistance.

When an ultrasonic vibration is applied to the arm part of the coil, it becomes a progressive wave and it spreads from the arm part to the coil part, and the rotor can be rotated according to the principle described in section one.

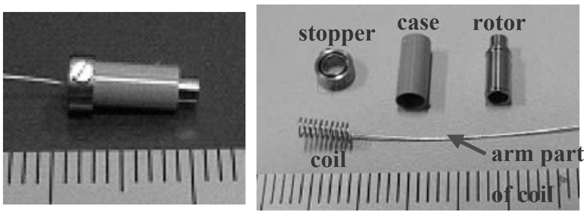


Fig. 2. Prototype of ultrasonic micromotor (left:overall view, right:exploded view)

4 Measurement of rotational speed and torque

Fig. 3 shows the apparatus for measuring the rotational speed of the micromotor. The stopper of the micromotor was fixed on the stage and the Langevin vibrator was used as a source of the ultrasonic vibration. A laser beam from the laser displacement meter is irradiated onto a small teeth of the gear (11 mm tip diameter and 7 mm length) which is connected to the tip of the rotor so as to reflect it intermittently, and this reflected light is caught by a laser displacement sensor whose data are stored in the memory of a note PC through the controller. Rotational speed was calculated from a series of pulse outputs. On the other hand, torque was calculated from a rotational angular acceleration and the moments of inertia of the rotor and gear (the following expression).

$$T = J\dot{\omega} \qquad (1.1)$$

T : *torque*

J : *moment of inertia*(*rotor*, *gear*)

$\dot{\omega}$: *angular acceleration*

Fig. 4 shows the results of the measurements of time and angular velocity. From the results, the shape in graph of angular velocity shows a first order lag and the regular rotational speed (approximately 250 rad/s) was seen at about 0.58 seconds in time. Moreover, the time-constant of the micromotor was 0.07 seconds. From the results, the increase and decrease of the value of angular velocity was large, hence, a stable rotation and a control of rotational speed are a problem in the future.

Fig. 5 shows the results of the measurements of rotational speed and torque. From the results, the starting torque is 14.4μNm and the maximum rotational speed is 2080 rpm. To verify the value of this torque, an experiment to wind up weight was carried out. From the results, it was possible to lift two one yen coin (approximately 20μNm is necessary to perform the lift). This value is somewhat different from the result of the calculated torque. However, it seems that the method of calculating torque has become a means for presuming torque without measuring the rough torque of the motor.

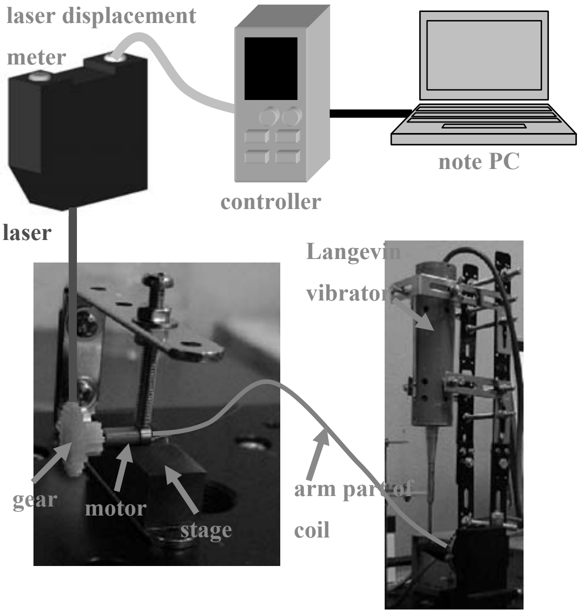


Fig. 3. Appratus for measuring rotational speed of micromotor

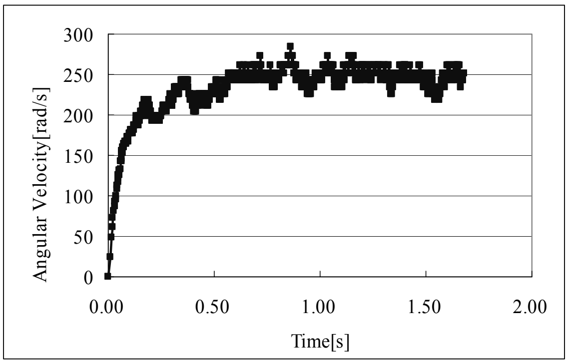


Fig. 4. Results of measurements of time and angular velocity

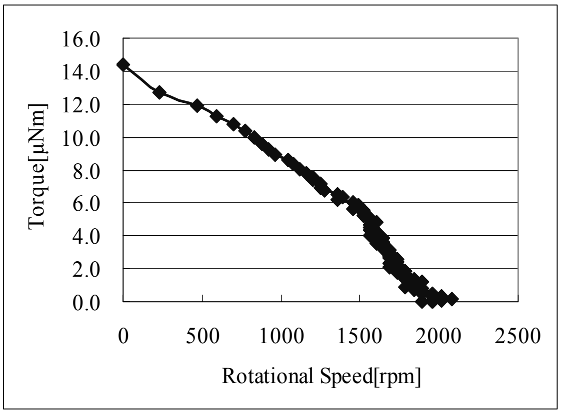


Fig. 5. Results of measurements of rotational speed and torque

5 Drive experiment in water

Fig. 6 shows an appearance of the drive experiment of the ultrasonic micromotor that is connected to a 2 mm diameter catheter (TerumoCo. , GC-N6JR350NH) in water. The gear (4 mm tip diameter and 5 mm length) is installed on the tip of the rotor, and the rotor is fixed to the stage. The drive of the micromotor was confirmed though the rotational speed decreased. As for the reason why rotational speed decreased, the attenuation of the ultrasonic vibration in the catheter is thought to be the reason.

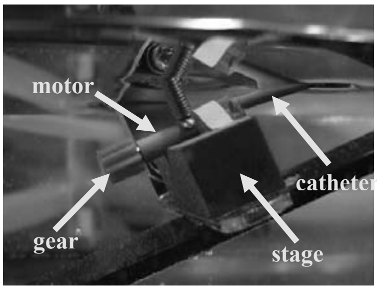


Fig. 6. The drive experiment in water

6 Principle of detection method

Fig. 7 shows the reception and transmission mechanisms of the ultrasonic vibration for blood vessel internal shape observation. A 20 MHz oscillator (external size, 1 mm,1 mm,0.2 mm) is used for the reception and transmission of ultrasonic vibration. Ultrasonic vibration can be transmitted and received by connecting this oscillator to the ultrasonic wave pulsar/receiver (PANAMETRICS-NDT company, MODEL5800), impressing the voltage of the pulse wave to the oscillator and using the piezoelectric effect of PZT. The direction of the transmitted ultrasonic wave is changed by a reflector and the ultrasonic wave is reflected in the blood vessel inner wall and is received by the oscillator following the same course. The shape of the waves is outputted to a digital oscilloscope (Tektronix Inc.,TDS2014) through the ultrasonic wave pulsar/receiver. The distance to the reflection side from the oscillator can be calculated by multiplying sound speed in water (1530 m/s) by the time from sending the ultrasonic vibration to the reception of it. By using this method, the shape of a blood vessel can be determined by measuring the distance to the reflection side and by installing the reflector in the rotor of the ultrasonic micromotor while rotating in the direction of the blood vessel circumference.

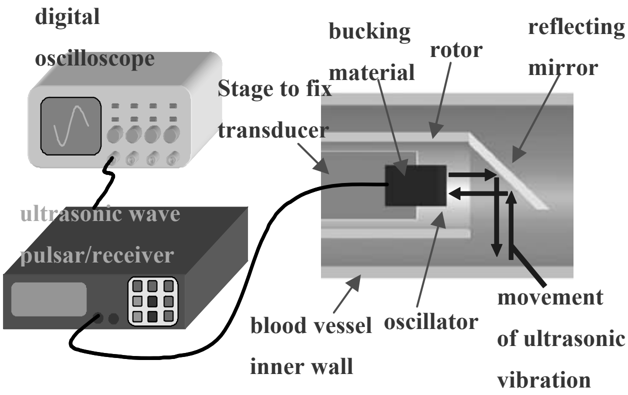


Fig. 7. Schematic diagram of detection method

7 Fundamental experiment of detection method

Fig. 8 shows the experimental apparatuses of the fundamental experiment that assumes the ultrasonic wave receiving and sending in a blood vessel. When the DC motor is rotated, the shaft rotates through the gear and the reflecting mirror installed in the shaft point rotates. The silicon tube was arranged by the reflector and the concentric circle and the oscillator was arranged short of the tip of the silicon tube. The ultrasonic vibration transmitted from the oscillator is radially rotated by the reflecting mirror and is reflected in the silicon tube inner wall and received by the oscillator. We examined whether the reception and transmission of ultrasonic vibration in this state to rotate the reflecting mirror were possible and whether the reception and transmission of ultrasonic vibration by the curved surface were possible in this experiment. The device shown in Fig. 8 was placed in a water tank and the actual experiment was done in water where the diffusion of the ultrasonic vibration was weak. Assumed a blood vessel, the silicon tube (4 mm inside diameter and 6 mm outside diameter) whose dynamic characteristics resemble those of a blood vessel was used (it is often used for the tube as a material for the medical treatment). The reflected wave was received as shown in Fig. 9. From the time from sending the transmission wave to obtaining the reflected wave, we were able to calculate the distance from the oscillator to the inner wall of the silicon tube and confirmed a 2 mm radius of the silicon tube. Moreover, when the rotational speed of the reflecting mirror was changed and the same experiment was carried out, we were able to confirm the shape of the reflected wave even at 2000 rpm, which was the maximum rotational speed of the prototype of the ultrasonic micromotor.

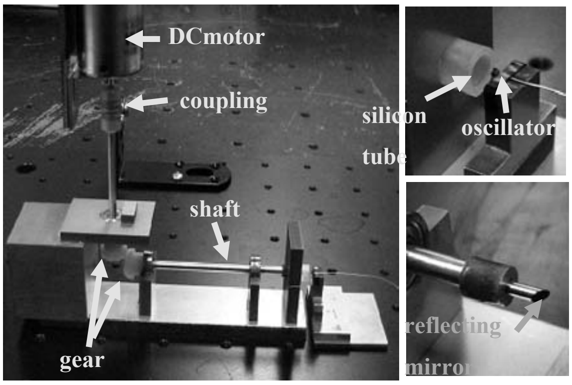


Fig. 8. Apparatus for measuring reflected wave

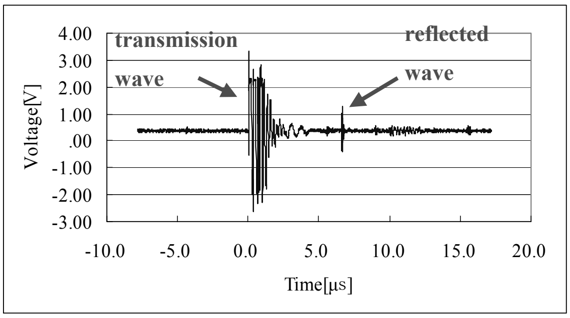


Fig. 9. Results of experiment

8 Future perspectives

As future perspectives, miniaturization of prototype of ultrasonic micromotor, improvement of torque, and stabilization of drive of micromotor are going to be performed. Moreover, ultrasonic wave signal reception and transmission experiment that uses parabolic mirror as reflecting mirror are going to be performed. A parabolic mirror can focus the ultrasonic vibration in the focus point, hence, the amplitude of the obtained reflected wave grows, and it is thought it is very effective for image processing. In addition, aiming at practical use, development of prototype of endoscope that combines reflecting mirror, oscillator, and ultrasonic micromotor is going to be performed. Next, using a prototype of endoscope, the internal observation in human blood vessel model is going to be peformed.

9 Conclusions

The torque-rotational speed characteristics of the prototype of an ultrasonic micromotor were examined, and the performance of the micromotor was examined, and it has been clarified that its starting torque was 14.4 μN, its maximum rotational speed was 2080 rpm and the time-constant of it was 0.07 seconds. Moreover the drive of the micromotor in water was also confirmed. However, its rotational speed and torque were low and its rotational speed was not stable, hence, it is necessary to improve the torque, rotational speed and stable drive of the micromotor for development of prototype of endscope.

A method for observing internal shape by the transmission and reception of ultrasonic vibration was proposed and a fundamental experiment for measuring reflected wave was performed. The reflected wave could be received in a silicon tube whose mechanical properties are similar to those of a blood vessel and the transmission and reception of ultrasonic vibration were possible in this state of the rotational speed of the micromotor (2080 rpm), thus, it is thought that its application to a prototype of endoscope that installs a reflecting mirror and an oscillator in the motor is possible.

10. References

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