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Basic Properties of Micropump with Magnetic Micromachine

Shinichi Hisatomi[1], Aya Yamazaki[1], Kazushi Ishiyama[1,*], Masahiko Sendoh[2],
Shin Yabukami[1], Shigeto Agatsuma[1], Keiko Morooka[1], and Ken Ichi Arai[1]

[1]*The Research Institute of Electrical Communiation, Tohoku University, Japan*
[2]*Miyagi Organization for Industry Promotion, Japan*

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A micropump with spiral-type magnetic micromachine was fabricated. When a rotating magnetic field was applied, the machine rotated and pumped a surrounding liquid. We experimentally examined the basic properties of this pump. We found that the pressure and the flow rate could be controlled by the rotating frequency, and this pump could work under wide range kinematic viscosity. In addition, we proposed a disposable pump system using the machine. When a plate installed a fluid channel and the machine was set on a stage for generating a rotating magnetic field, the machine worked as the pump.

Keywords : micropump, magnetic micromachine, rotating magnetic field, disposable pump system

1. Introduction

Micropumps are the micro fluid devices which can pump the liquid quantitatively. Micropumps are required in mTAS (micro Total Analysis System), automatic medication systems and so on. The principals of the previous micropumps are using piezoelectric materials [1], SMA (Shape Memory Alloy) [2], magnetic systems [3], etc. These micropumps can generate a pressure of several kPa. However, these micropumps are large as several mm in size, and can pump only the liquid with low kinematic viscosity. Furthermore, the pumps require power supply cables. Therefore, it is difficult to miniaturize and to pump a liquid with high kinematic viscosity. Moreover, the pumps using electrophoretic devices can't pump the liquid quantitatively.

In this study, we proposed a micropump using a spiral-type magnetic micromachine. The magnetic micromachine requires no power supply cables, no batteries, and no controlling systems on the machine body. As the magnetic micromachine works wirelessly, we can obtain a wireless micropump. In addition, the magnetic micromachine works under very wide range kinematic viscosity of the liquid. For discussing kinematic viscosity of the liquid, the Reynolds number *Re* (the ratio of inertial force to viscous force) is an important parameter. The Reynolds number is given by

$$\mathrm{Re} = \frac{XU}{\nu} \qquad (1)$$

where X is a diameter of the fluid channel, U is velocity of a flowing fluid, and ν is kinematic viscosity of the liquid. In our previous works, we studied about the spiral shaped magnetic micromachines and found that the spiral-type structure were applicable under very wide range of Reynolds numbers ($10^{-7} < \mathrm{Re} < 10^{3}$) experimentally and analytically [4-6]. Using this unique property, the machine could work in liquid or soft jells [7]. So this micropump is expected to work at the liquids with wide range of kinematic viscosity and to be suitable for the miniaturization.

We have examined the basic properties of the pump, and we have found that the produced pressure could be controlled by the rotating frequency [8]. In this study, we examined the properties of the pump such as the pressure and the flow rate with variations of the rotating frequency and kinematic viscosity of the liquid. In addition, we proposed a disposable pump system using the magnetic micromachine.

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*Corresponding author: Tel: +81-22-217-5488,
Fax: +81-22-217-5728, e-mail: ishiyama@riec.tohoku.ac.jp

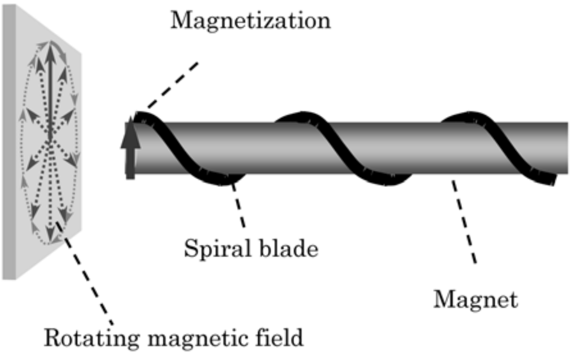

Fig. 1. Schematic view of the magnetic micromachine.

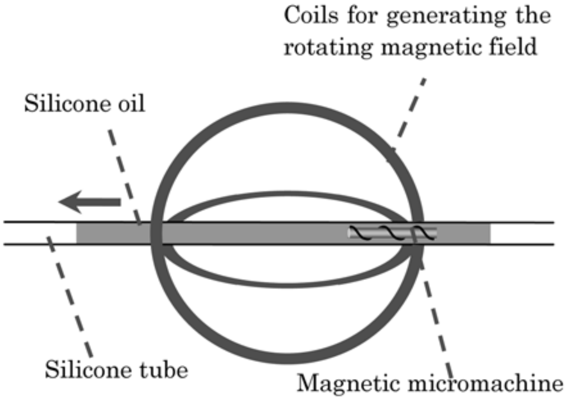

Fig. 2. Schematic view of the experimental equipment.

2. The Micropump with the Rotating Magnetic Field

Fig. 1 shows a schematic view of the spiral-type magnetic micromachine for the micropump. The micromachine was composed of an isotropic NdFeB magnet (ϕ 0.5 × 10 mm) and a spiral blade made by a tungsten wire (ϕ 0.25 mm). In this experiment, we used silicone oils with several kinds of kinematic viscosity, and a silicone tube with the inner diameter of 1.6 mm. The magnetic field strength was 1.6 kA/m. When a rotating magnetic field was applied, the machine rotated synchronously because the isotropic easy axis of the magnet was diametrical direction and magnetized to the direction as shown in Fig. 1. Fig. 2 shows the schematic view of the micropump. When the machine rotated, the spiral blade produced a thrust force in the oil. The machine stayed and pumped the oil at the balancing point of the thrust force and the force by the magnetic field gradient at the edge of the exciting coils.

Fig. 3 shows the relation between the pressure and the flow rate with variations of the rotating frequency. In the experiment, we used silicone oil with kinematic viscosity of 10 mm^2/s. The machine pumped the oil in the rotating frequency less than 103 Hz. At over 103 Hz, the thrust force of the machine exceeded the force by the magnetic field gradient, and the machine escaped from the coils. It was found that the flow rate was linearly decreased with the pressure at the same rotating frequency. Moreover, the pressure and the flow rate increased with the rotating frequency. We forecast that this relation would be changed by the shape of the machine, the relation between the inner diameter of the fluid channel, and the size of the machine. Therefore, it is necessary to optimize the shape of the pump.

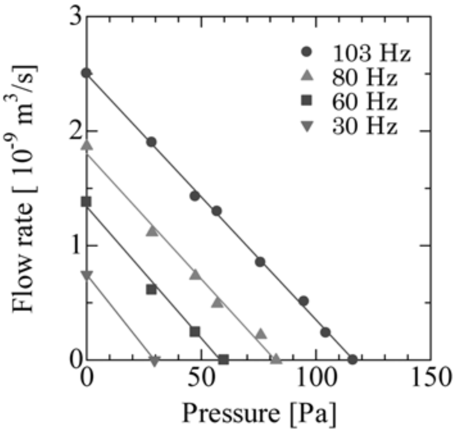

Fig. 3. Relation between pressure and flow rate with variations of the rotating frequency.

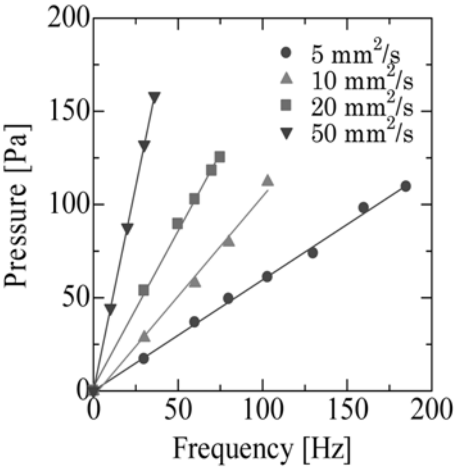

Fig. 4. Relation between frequency and pressure with variations of the kinematic viscosity.

Fig. 4 shows the relation between the rotating frequency and the pressure with variations of the kinematic viscosity. The pressure increased in proportion to the rotating frequency. The higher pressure was obtained in the higher kinematic viscosity at the same frequency

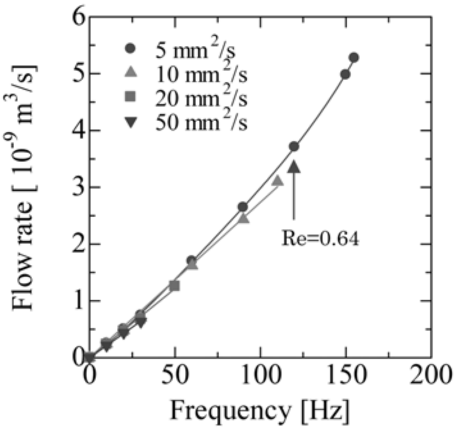

Fig. 5. Relation between frequency and pressure with variations of the kinematic viscosity.

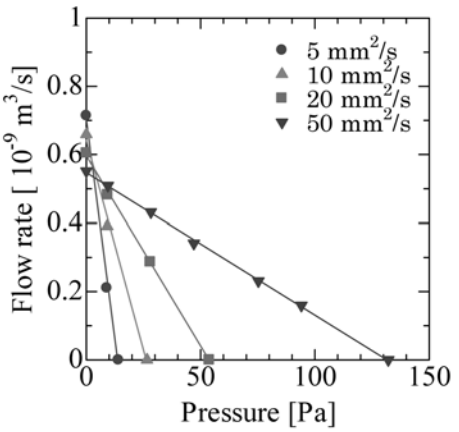

Fig. 6. Relation between pressure and flow rate with variations of the kinematic viscosity.

because the shearing stress at the surface of the machine increased with increasing kinematic viscosity. Fig. 5 shows the relation between the rotating frequency and the flow rate with variations of the kinematic viscosity. The flow rate increased in proportion to the rotating frequency in each kinematic viscocity, and the flow rate was equal at the same rotating frequency regardless of the kinematic viscosity of the oil. In this experiment, Reynolds numbers were in a range from 0.0056 to 0.89.

The results shown in Fig. 5 was explained by Hargen-Poiseuille's law [9] as shown below.

$$Q = \frac{\Delta P}{8\mu l}\pi r_0^4 \tag{2}$$

where Q is the flow rate, ΔP is the differential pressure, μ is the kinematic viscosity of the liquid, l is the length of the liquid installed in the fluid channel, and r_0 is the diameter of the fluid channel. l and r_0 was constant. The pressure difference ΔP in this equation describes the generated pressure by the machine in this experiment. The generated pressure increased in proportion to the kinematic viscosity because the Reynolds number was much smaller than 1 and the inertia force could be neglected. Therefore the flow rate Q was independent of the kinematic viscosity μ.

Fig. 6 shows the relation between the pressure and the flow rate with variations of the kinematic viscosity. In this experiment, the rotating frequency was 30 Hz. It was found that the flow rate was linearly decreased with the pressure at the same kinematic viscosity. Moreover, this pump could work under wide-range kinematic viscosity of the oil.

3. Disposable Pump System

The micropump in this study works without wire. Therefore, we proposed a disposable pump system using this micromachine. When a disposable plate with a fluid channel and the machine was set on a stage for generating a rotating magnetic field, the micropump could pump the

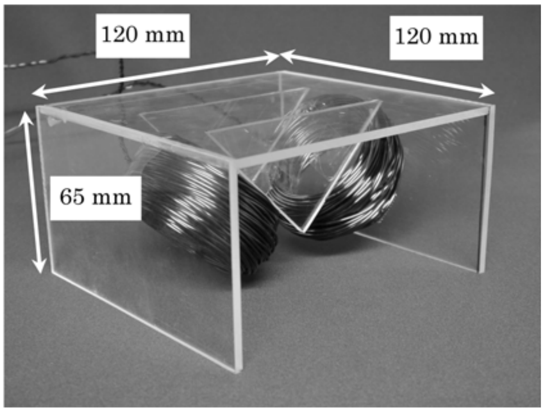

Fig. 7. Photogragh of the stage for generating the rotational magnetic field.

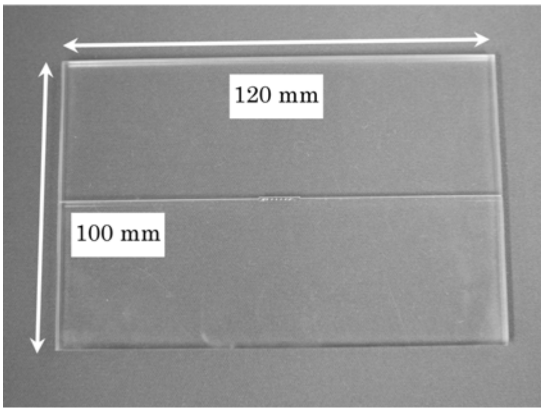

Fig. 8. Photogragh of a plate with a fluid channel.

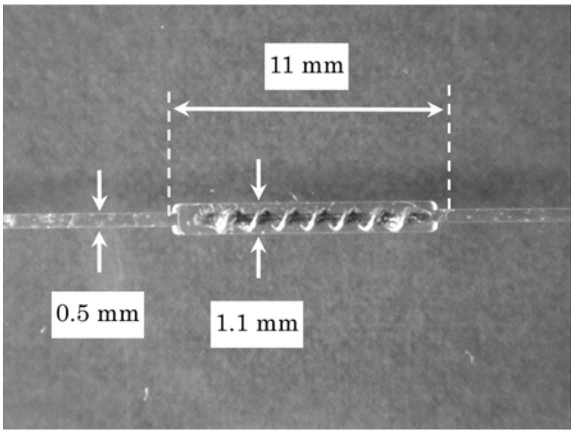

Fig. 9. Photogragh of the machine and a space for installing the machine in the fluid channel.

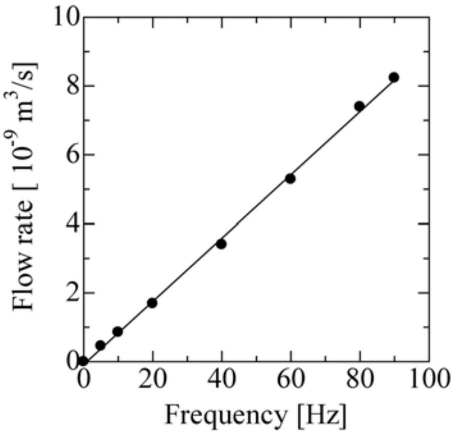

Fig. 10. Relation between the rotating frequency and flow rate in a disposable pump system.

fluid in the channel.

Fig. 7 shows the photograph of a stage for generating a rotating magnetic field. The size of the stage was 120 × 120 × 65 mm, and the stage included two coils. Controlling the current of the two coils, we can generate a rotating magnetic field on the stage. Fig. 8 shows the photograph of a plate with a fluid channel. The size of the plate was 120 × 100 × 5 mm, and it was made of acrylic resin. We fabricated the fluid channel and the space for installing the machine in the fluid channel. The size of the fluid channel was width of 0.5 mm, depth of 1.1 mm. The size of the space for the machine was 11 × 1.1 × 1.25 mm. Fig. 9 shows the photograph of the space for installing the machine in the fluid channel. We installed the machine (ϕ 1.0 × 10 mm), and poured a silicone oil with kinematic viscosity of 5 mm^2/s in the fluid channel.

When the plate with the fluid channel was set on the stage, the machine started to work by the rotating magnetic field and worked as the pump. The pump worked up to 90 Hz with the rotating magnetic field of 1.6 kA/m. Fig. 10 shows the relation between the rotating frequency and the flow rate. The flow rate increased in proportion to the rotating frequency and the maximum flow rate was 8.3×10^{-9} m^3/s. Compare with the result using tube as shown in Fig. 5, the flow rate in this result was larger. This result indicates the distance between the machine and the wall of the channel is very important parameter. The smaller the distance, the larger the flow rate will be obtained. As a result, the flow rate could be controlled by the rotating frequency in this system.

4. Summary

The micropump with the spiral-type magnetic micromachine was fabricated. We quantitatively clarified the relation between the pressure and the flow rate of the pump. The relation between the pressure and the flow rate was linearly in each kinematic viscosity, and this pump could work under wide range kinematic viscosity of the liquid. In addition, to obtain a disposable pump system, we fabricated a stage for generating the rotating magnetic field and a plate with the fluid channel. The pump worked only when the plate was set on the stage. In this system, the flow rate could be controlled by the rotating frequency, and the maximum flow rate was 8.3×10^{-9} m^3/s. This unique character of this pump is suitable for applications of microfluidics and bioengineering systems.

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