

Fabrication and Testing of a Small Pump Composed of a Magnet and an Elastic Plate

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Abstract— A new type of micro-pump using an angular movement of an elastic plate is proposed. The moving part of the pump consists of a small permanent magnet attached to an elastic plate. If an alternating magnetic field is applied, the magnet vibrates angularly due to magnetic torque and then the polyimide film causes a unidirectional movement of fluid. A cm-size pump based on this mechanism has been constructed and tested. The maximum flow rate of 750 ml/min and the maximum pressure of approximately 4.2 kPa were achieved when ethyl alcohol was used as a working fluid.

Index Terms— angular movement, micro-pump, permanent magnet, magnetic torque.

I. INTRODUCTION

Recently, a great deal of effort has been made on a micro-pump for a micro liquid handling system in medical and industrial fields. Most of the micro-pumps reported so far are a membrane type [1], [2], composed of a thin flexible membrane and passive check valves, and enable a precise control of extremely small amounts of fluids in the order of 10^{-6} l/min. The driving force used is mainly electrostatic, piezoelectric, and pneumatic. On the other hand, a micro-pump handling large amounts of fluids is preferred in some applications such as a compact liquid cooling system for electronics. However, little attention has been given to the micro-pump for large flows because a suitable pumping micro-mechanism has not been developed.

The final goal of this study is to realize a micro-pump handling large amounts of fluids. The pump proposed here has a unique mechanism based on the swimming POD (Power Operated Device) [3], composed of a small permanent magnet attached to a

flexible plate. The POD was developed for medical purposes such as a drug delivery and driving catheters in 1970's. It has been reported that the POD could swim at a high speed over 30 cm/s in a pipe under alternating magnetic fields. Looking at such a swimming performance from a different angle, we expect that this mechanism may be useful for a micro-pump handling large amounts of fluids. In this paper, the structure and basic characteristics of the trial cm-size pump based on the POD are described.

II. DEVICE STRUCTURE

Fig. 1 shows a schematic view of a trial pump. It has two segments; a moving part and an aluminum chamber. The moving part consists of a cylinder NdFeB magnet, 5 mm in height and 6 mm in diameter, attached to an elastic plate. The magnet is magnetized along the length direction. The elastic plate is made of a polyimide film, 0.125 mm in thickness, 20 mm in length, and 10 mm in width. At the connecting point of the magnet with the plate, a narrow pipe was fixed as

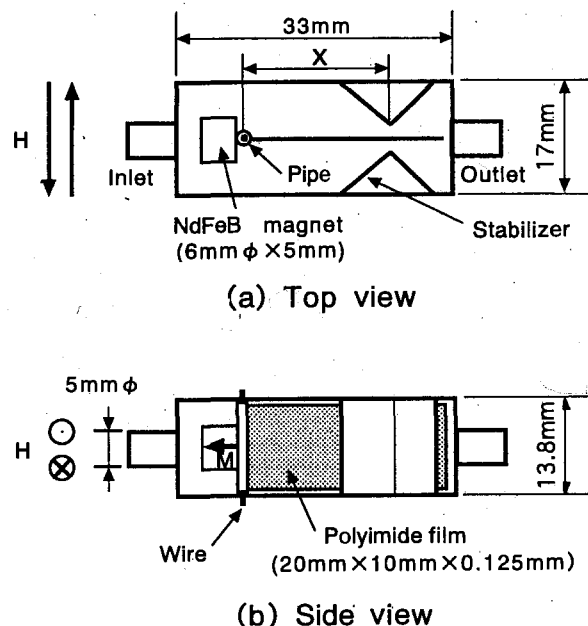


Fig.1 Schematic view of the trial pump.

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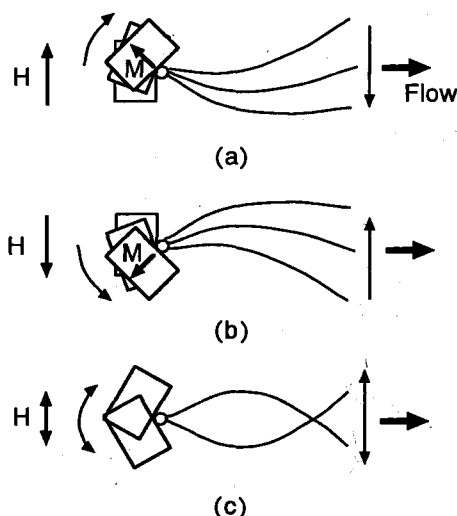


Fig.2 Behavior of the moving part under the alternating magnetic field.

a pivot. The aluminum chamber is a rectangular prism with an inlet and an outlet whose diameter is 5 mm. The size of the chamber is as indicated in Fig.1. Inside the chamber, two figure-L plates are installed as a stabilizer in order to prevent an unstable vibration of the moving part. The distance of the stabilizers is 2 mm. The effect of the stabilizers is taken up in the next chapter. The moving part is mounted in the chamber through the pipe. The total mass of the pump is approximately 8.5 g.

When an alternating magnetic field is applied in the arrow direction, the magnet vibrates angularly around the pipe due to magnetic torque, given by the vector product of the magnetic moment and the external magnetic field. Then the polyimide film also vibrates angularly, as shown in Fig. 2(a) and (b), and causes a unidirectional movement of the fluid toward the outlet. The important point to note is that the lateral movement of the polyimide film changes with frequency. For example, the vibration has a wave node at higher frequencies, as shown in Fig. 2(c).

III. RESULTS AND DISCUSSION

In this study, the flow rate and the output pressure were examined using ethyl alcohol as a working liquid. The output pressure was measured by the height from the inlet water level to the discharge water level. In order to examine the actuation of the moving part under a uniform magnetic field, a Helmholtz coil was used as a driving unit and was arranged at both sides

of the pump. The gap and outside diameter of the coil are 20 mm and 80 mm, respectively. Of course, it is possible to install a driving unit with an iron core in the pump. This point is under investigation.

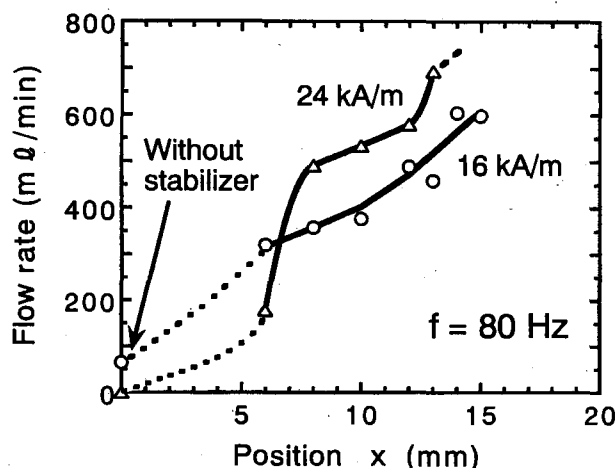


Fig.3 Flow rate as a function of the position of the stabilizers.

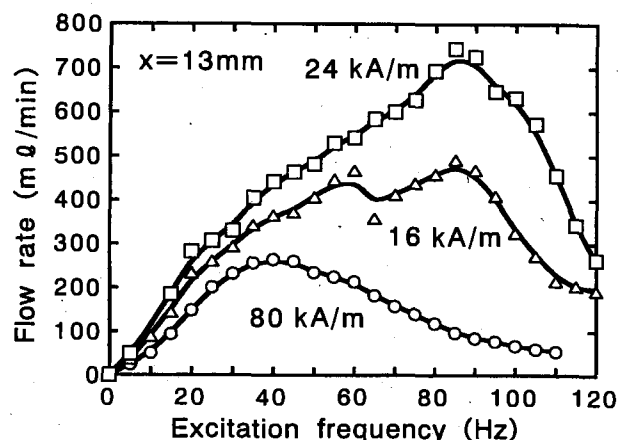


Fig.4 Flow rate as a function of the excitation frequency.

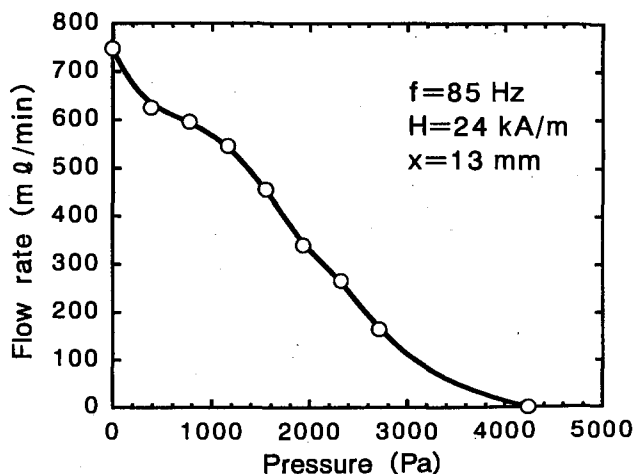


Fig.5 Relationship between the flow rate and the pressure.

First of all, we examined the effect of the stabilizers installed inside the chamber. Without the stabilizers, the vibration of the polyimide film became unsymmetrical with respect to the center line of the chamber, especially at higher frequencies, which caused a vortex in the chamber. As a result, the flow rate leveled off or decreased. The function of the stabilizers is to prevent such an unstable behavior by supporting the vibration from both sides. In this case, it is important to find a position, where the decrease in the amplitude of the vibration is minimum.

Fig. 3 shows the flow rate at 0 Pa as a function of the distance, x , of the stabilizers from the pivot when the alternating magnetic fields of 8 kA/m and 16 kA/m were applied at 80 Hz. Obviously, the stabilizers greatly improved the flow rate. In addition, the flow rate showed the tendency to increase with x in a region $x = 6-15$ mm. This result is linked with the lateral movements of the vibration previously mentioned. Because the vibration of the polyimide film at 80 Hz had a wave node around $x = 14-15$ mm, the stabilizers installed there maintained the amplitude of the vibration. This result indicates that it is desirable to install the stabilizers around the wave node. But the vibration under 24 kA/m was unstable at $x > 13$ mm because the whole polyimide film frequently fell in the inlet side off the stabilizers. In the following examination, therefore, we examined the pump performance for the stabilizers installed at $x = 13$ mm.

Fig. 4 shows the flow rate at 0 Pa as a function of the excitation frequency when the alternating magnetic fields of 8 kA/m, 16 kA/m, and 24 kA/m were applied. The flow rate increased with increasing the frequency and reached a peak at a certain point. Afterwards the further increase in the frequency caused the flow rate to gradually decrease according to the decrease in the amplitude of the vibration. The maximum flow rate of 750 ml/min was obtained when 24 kA/m was applied at 85 Hz.

Fig. 5 shows the relation between the pressure and the flow rate when 24 kA/m was applied at 85 Hz. The flow rate decreased monotonously with increasing the pressure and reached zero at 4.2 kPa. This result indicates that the maximum output pressure of the trial pump was 4.2 kPa.

Table I compares the performance of the trial pump with two other kinds of cm-size magnetic pumps; an electromagnetic-drive plunger pump [4] and a magnetostriction-based reciprocating pump [5]. The pump presented here has an advantage of handling the large amounts of liquids although its output pressure is low compared with others.

TABLE I
COMPARISON OF THE PERFORMANCE FOR CM-SIZE MAGNETIC PUMP.

Type	Size (mm)	Max. flow rate (ml/min)	Max. pressure (kPa)
This work	13.8×17×33	750	4.2
REC plunger pump	φ 15×75	200	30
Magnetostriction-based pump	φ 33.5×85.7	81	800

In addition, the pump proposed here has the following merits: the valveless simple structure makes it possible to pump liquids with solid particle contents; the wireless operation without electrodes is available by using external magnetic field.

IV. CONCLUSIONS

We proposed a new pumping mechanism composed of a permanent magnet and an elastic plate. The first trial cm-size pump based on this mechanism was fabricated and tested under the alternating magnetic field. The maximum flow rate of 750 ml/min and the maximum pressure of 4.2 kPa were successfully achieved.

Forthcoming efforts will focus on the optimum design for the moving part and the inner shape of the chamber. Parallel efforts will downsize the pump to the mm size.

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