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A NEW TYPE OF MICROPUMP DRIVEN BY A LOW ELECTRIC VOLTAGE

GUO Shuxiang (郭书祥)[1,†] ASAKA Kinji[2]

[1](*Dept. of Intelligent Mechanical Systems Eng'g, Kagawa University, Takamatsu,* 761-0396, *Japan*)

[2](*National Institute of Advanced Industrial Science and Technology* (*AIST*), *Osaka* 563, *Japan*)

ABSTRACT: In this paper, we propose a new prototype model of a micro pump using ICPF (Ionic Conducting Polymer Film) actuator as the servo actuator. This micro pump consists of two active one-way valves that make use of the same ICPF actuator. The overall size of this micro pump prototype is 12mm in diameter and 20 mm in length. The actuating mechanism is as follows: (1) The ICPF actuator as the diaphragm is bent into anode side by application of electricity. Then the volume of the pump chamber increases, resulting in the inflow of liquid from the inlet to the chamber. (2) By changing the current direction, the volume of the pump chamber decreases, resulting in the liquid flow from the chamber to the outlet. (3) The ICPF actuator is put on a sine voltage, the micro pump provides liquid flow from the inlet to the outlet continuously. Characteristic of the micro pump is measured. The experimental results indicate that the micro pump has the satisfactory responses.

KEY WORDS: micro machine, micropump, ionic conducting polymer film (ICPF) actuator, medical applications, biotechnology

1 INTRODUCTION

Intracavity intervention is expected to become increasingly popular in the medical practice, both for diagnosis and for surgery. As we know, many kinds of microactuator such as an electrostatic actuator, a piezoelectric actuator, a giant magnetostrictive alloy (GMA) actuator, a shape memory alloy actuator, a polymer actuator and an optical actuator have been actively investigated for their potential applications to micromachine technologies. In the medical field and in biotechnology, a new type of micro pump that can supply micro liquid flow has urgently been demanded[1,2]. The micro pump is one of the micro and miniature devices, which is installed with sensing and actuating elements. It can supply micro liquid flow. Recently, several types of micro pump using polymer actuator and PZT actuator have been reported so far[3~5]. However there are some problems, such as compact structure, low response, leaking electric current, safety in body and so on. The micro pump with supplying micro liquid flow and safety has never been developed so far. It is our purpose to develop a type of micro pump that has the characteristics of flexibility, driven by a low voltage, good response and safety in body. In this paper, we propose a new prototype model of a micro pump using ICPF (Ionic Conducting Polymer Film) actuator as the servo actuator. This micro pump consists of two one-way valves that make use of the same ICPF actuator. The overall size of this micro pump prototype is 10 mm in diameter and 20 mm in length. The actuating mechanism is as follows. ICPF actuator is made from the film of perfluorosulfonic acid polymer (Nafion 117, du Pont and company) chemically plated on it is both sides with platinum. In many points, ICPF actuator is superior to usual polymer gel actuator such as fast response, driven by low voltage (about 1.5 V) in wet condition without electrolysis, safety in body and so on[6]. This paper describes the new structure and the motion mechanism of a micro pump using ICPF actuator and discusses the possibility of the micropump.

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† E-mail: guo@eng.kagawa-u.ac.jp

2 STRUCTURE OF MICROPUMP

2.1 Total Structure of the Micropump

Figure 1 shows the basic structure of the developed micropump using ICPF actuator. This pump consists of the driving ICPF actuator as the diaphragm (A), pump chamber (B) and two one-way valves driven by ICPF actuator installed on one side of the pump chamber(C). ICPF actuators are installed in serial structure for supplying a large flow range. The photo of the developed micropump is shown in Fig.2.

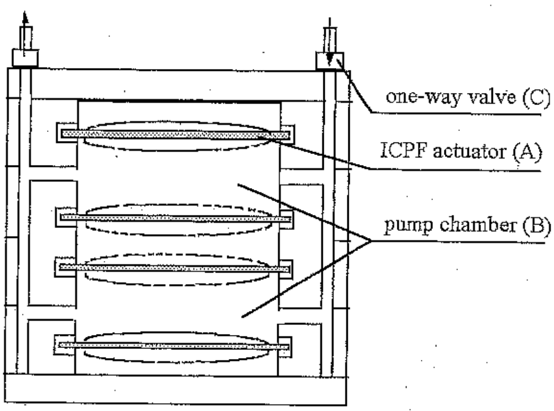


Fig.1 Total structure of the micropump

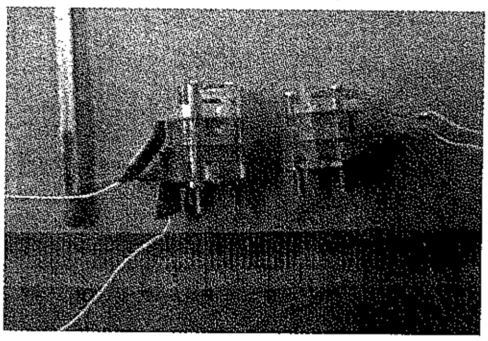
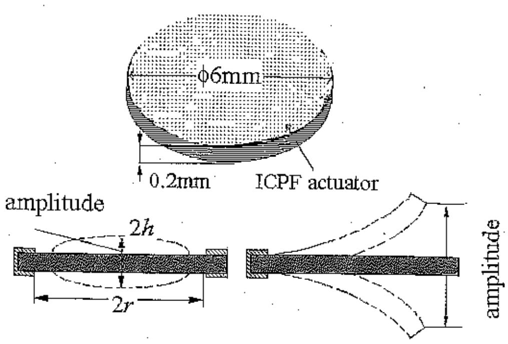


Fig.2 View of the developed micropump

2.2 ICPF Actuator

ICPF actuator is made from the film of perfluorosulfonic acid polymer (Nafion 117, du Pont and company) chemically plated on it is both sides with platinum (one side is 0.003 mm in thickness). It is known as an ion exchange membrane. It is a kind of high polymer gel actuator, works only in water and in wet condition. The ICPF is bent into anode side when the about 1.5 V voltage is put onto its surfaces. Displacement of the ICPF is proportional to the electrical voltage in put on its surface as the swelling of polymer gels. It is because that electrical condenser is generated on the polymer membrane. Circular ICPF actuator used for micro pump is shown in Fig.3. Amplitude ($2h$) is obtained by using sine wave voltage input.

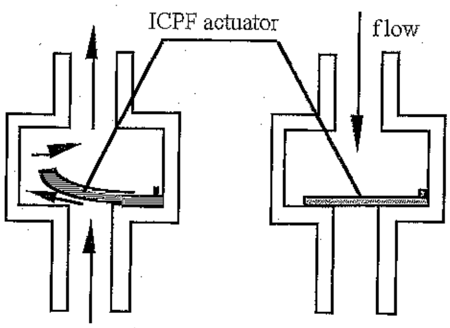


(a) For the pump chamber (b) For one-way valve

Fig.3 Circular ICPF for the micropump

3 MOTION MECHANISM OF THE MICROPUMP

The developed micropump has two active one-way valves. The structure of one-way valve is shown in Fig.4. The valve designed in the shape of taper, has a through hole leading from the tip to outside. When the ICPF actuator is bent into the flow direction driven by using the same sine voltage, the solution flows into the valve from the through hole. And it flows out through an outlet tube. It is prevented that the solution flows from the outlet tube into the valve, since through hole is closed by the ICPF actuator.



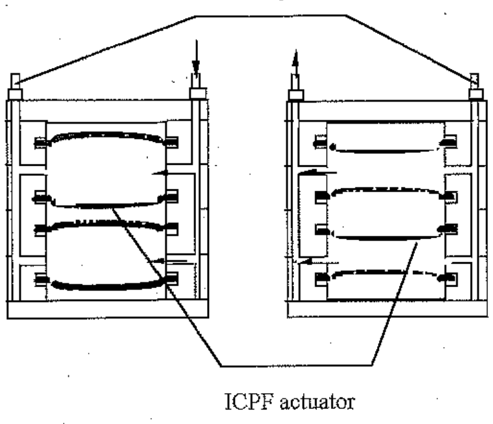
(a) Feed forward (b) Back forward

Fig.4 Working mechanism of the one-way valve

The actuating mechanism of micropump is as follows.

(1)The ICPF actuator as the diaphragm is bent into anode side by application of electricity. Then the volume of the pump chamber increases, resulting in the inflow of solution from the inlet to the chamber as shown in Fig.5(a).

(2)By changing the current direction, the volume of the pump chamber decreases, resulting the solution flow from the chamber to the outlet as shown in Fig.5(b).



(a) Inlet of solution (b) Outlet of solution

Fig.5 Mechanism of micropump using ICPF actuator

(3) The ICPF actuator is driven by the same sine voltage input, the micropump provides solution flow from the inlet to the outlet continuously.

4 CHARACTERISTIC MEASUREMENT

4.1 Measurement System

The electric voltage set onto ICPF actuator can be controlled by a computer. The electrical current is measured by a galvanometer. The bending displacement of ICPF actuator in center h is measured by a laser displacement sensor. The bending amplitude ($2h$) of circular ICPF actuator can be obtained driven by sine voltage input. Measurement System is shown in Fig.6.

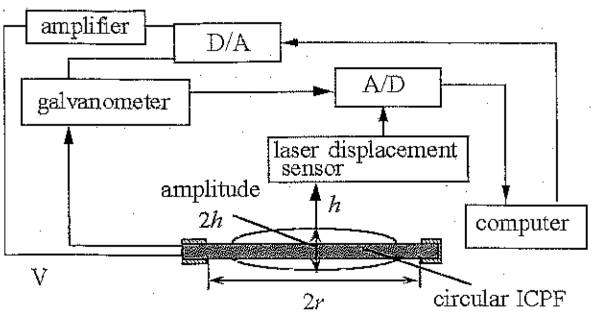


Fig.6 Measurement system

4.2 Characteristic of the One-way Valve

By using the measurement system as shown in Fig.6, the following characteristics of the one-way valve shown in Fig.7 are measured. Firstly, we measured the response characteristic and the maximum displacement of the one-way valve by changing the frequency of voltage input. Secondly, the maximum force is also measured by changing the input voltage, and by changing the frequency of voltage input. The experimental results are shown in Fig.8. From these experimental results, it is known that the maximum displacement and maximum force are in inverse pro-

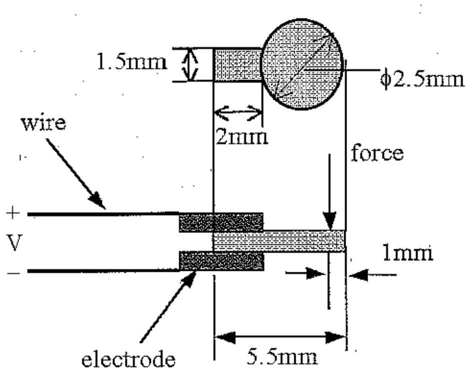
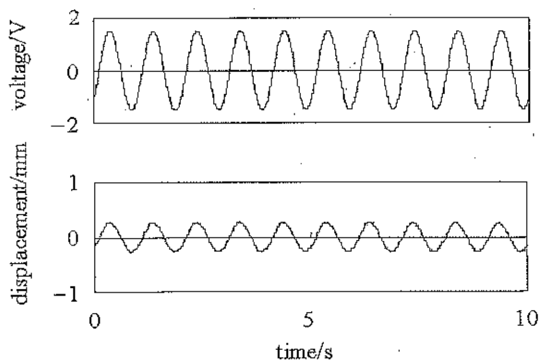
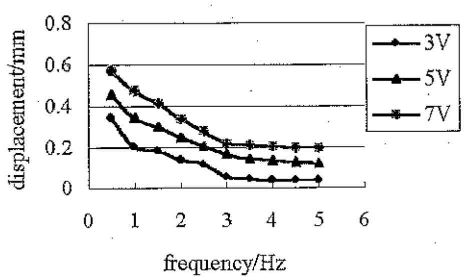


Fig.7 Circular ICPF of the one-way valve

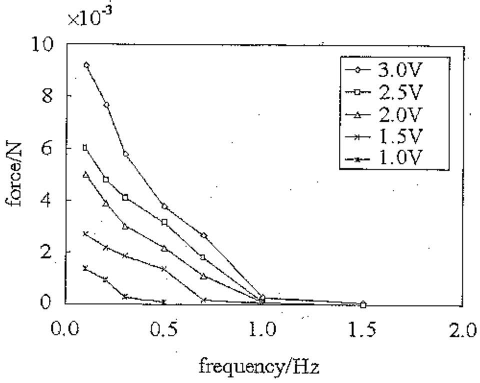


(a) Response characteristic (1.5 V, 1 Hz)



(b) Maximum displacement (in air)

Fig.8 Characteristic of the one-way valve



(c) Force characteristic

Fig.8 Characteristic of the one-way valve (continued)

portion to the frequency, nearly proportional to the input sine voltage, respectively, and the active one-way valve is effective for the micropump driven by electrical application.

4.3 Chamber Characteristic

By using the measurement system, the following chamber characteristics are also measured. Firstly, we measured the maximum displacement of circular ICPF actuator as shown in Fig.9 in the center point by changing the frequency of sine voltage input. Secondly, the maximum displacement and the maximum current are also measured by changing the input voltage. The experimental results are shown in Fig.10 and Fig.11. From these experimental results, it is known that the maximum displacement is in inverse proportion to the frequency, and nearly proportional to the input sine voltage, respectively. The maximum current is nearly proportional to the input voltage. So, we can just adjust the frequency and electric voltage to control the bending displacement of the pump chamber.

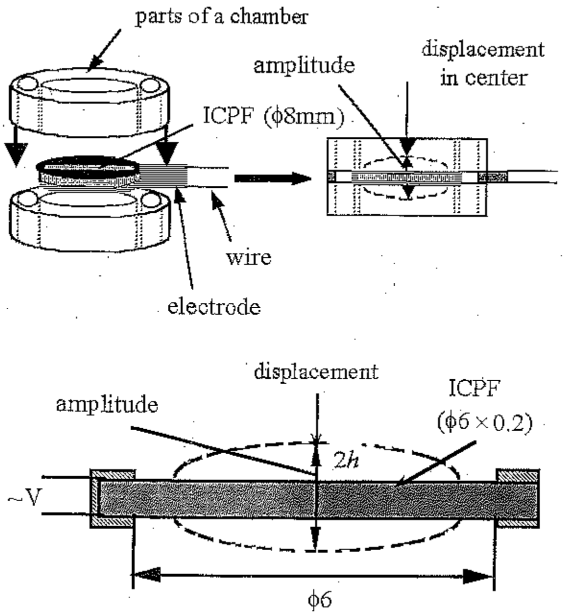
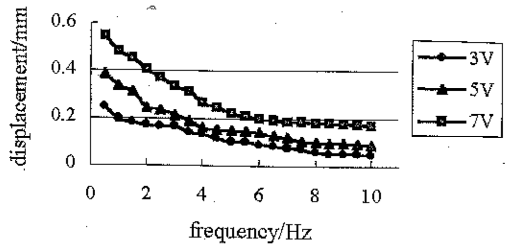
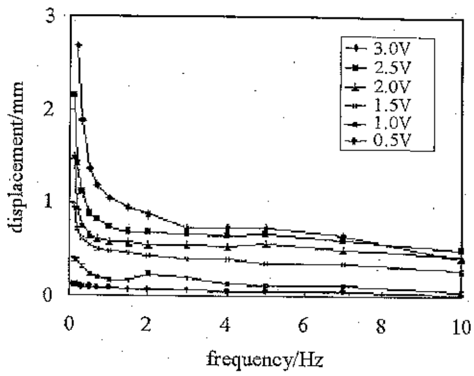


Fig.9 ICPF actuator for the pump chamber



(a) Maximum displacement (sine voltage)



(b) Maximum displacement (pulse voltage)

Fig.10 Maximum displacement of the pump chamber

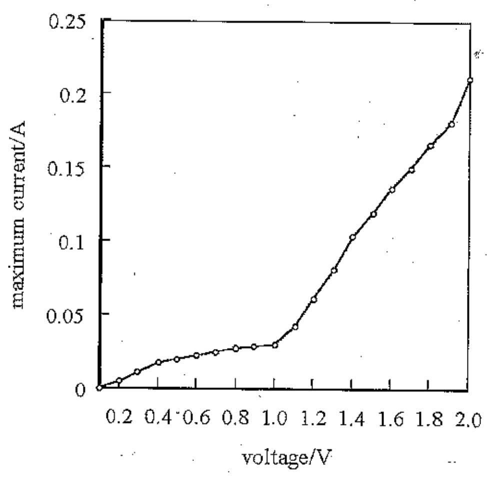


Fig.11 Maximum electric current (in air)

5 FLOW EVALUATION OF MICROPUMP

When micropump is driven by a sine voltage input. It is very important that to evaluate the flow output by changing the frequency of sine voltage input. In this paper, we present a calculation method of the micropump using ICPF actuator based on the ICPF bending characteristic. In order to obtain the theoretical equations of flow characteristic, the following conditions to the ICPF actuator are assumed.

(1) The Circular ICPF actuator is bent in a certain fixed curvature (a spherical model). The spherical radius is R.

(2) While the Circular ICPF actuator is driven by a sine voltage input, the amplitude is $2h$.

(3) The diameter of the flow pass is d, and l is the length of the flow pass.

Based on the above assumptions, the model of flow evaluation is shown in Fig.12. R as shown in Fig.12 is the spherical radius of ICPF actuator; O point is the sphere center. We intend to express the flow output of a cycle ΔV_0 in terms of amplitude ($2h$), parameter r and so on. The following Eqs.(1)~(4) can be obtained.

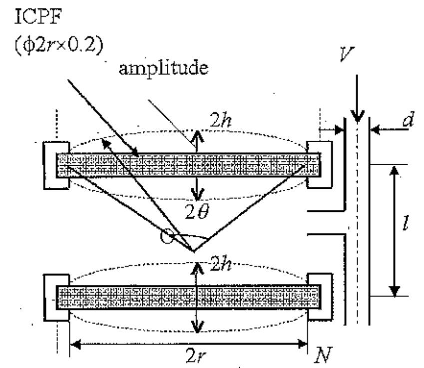


Fig.12 Model of the flow evaluation

Where N is the ICPF actuator number used for micropump, f is the frequency of a driving sine voltage input; Q is the flow per minute.

The pressure loss can be evaluated by Eq.(5). Where μ is the coefficient of the fluid viscosity. On the basis of Eq.(3), the flow of micropump can be calculated as shown in Fig.13. Based on the calculated experiments, it is known that the micro flow can be obtained by selecting suitable parameters.

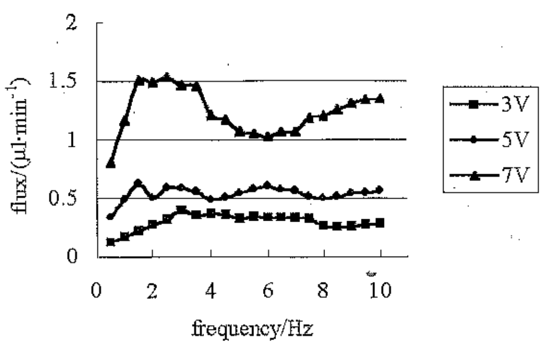


Fig.13 Calculated results of the flow evaluation

$$R = \frac{r^2 + h^2}{2h} \qquad 2\theta = 2\arccos\frac{R-h}{R} \tag{1}$$

$$\Delta V_0 = \frac{\pi h(3r^2 + h^2)}{6}N \tag{2}$$

$$Q = 60f\Delta V_0 = 60fN\frac{\pi h(3r^2 + h^2)}{6}(\mu l/\text{min}) \tag{3}$$

$$V = fN\frac{2h(3r^2 + h^2)}{3d^2}(\text{mm/s}) \tag{4}$$

$$\Delta p = \frac{32\mu l}{d^2}V = fN\frac{64\mu l h(3r^2 + h^2)}{3d^4}(\text{Pa}) \tag{5}$$

6 PROTOTYPE MICROPUMP

The prototype of developed micropump using ICPF actuator is shown in Fig.2. The size of the pump is 13 mm in diameter, 21 mm in length (18mm without tube connector) as shown in Table 1. The micropump is mainly made of acryl material, because the physiological saline is used for the experiments. 2 circular ICPF actuators are used for pump chamber ($N = 2$).

Table 1 Specification of prototype micropump

Size	13 mm×23 mm
Weight	2.1 g
Material	Acryl
Flow	4.5 μl/min (rated) 37.8 μl/min (max)
Actuator	ICPF actuator
Power Supply	electricity (e.g.1.5 V, 0.12 A)

On the basis of Eq.(3), the flow of micropump is calculated by using the experimental max. displacement as shown in Fig.9 ($N = 2$, $r = 3$ mm). By using the flow measurement system shown in Fig.14. We also carry out the experiment of flow measurement in 1.5 sine voltage input by changing the frequency from

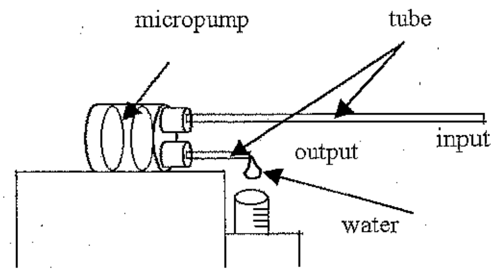


Fig.14 Measurement system of the flow evaluation

0.1 Hz to 15 Hz. The experimental results and calculation results of flow output of micropump are shown in Fig.15. The experimental results show that the flow 4.5 μl/min~37.8 μl/min can be obtained by changing the frequency.

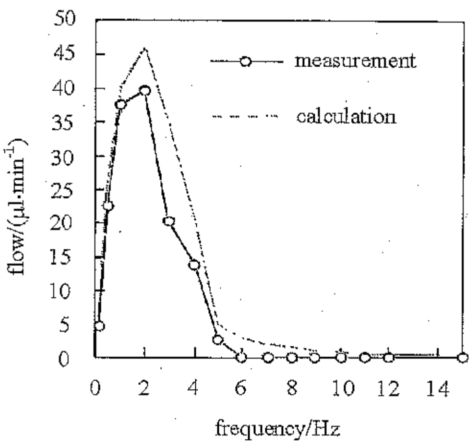


Fig.15 Experimental results of the micropump (1.5 V)

7 CONCLUSIONS

In this paper, we propose a new prototype model of micropump using ICPF actuator. We also discussed the structure, characteristic measurement, flow evaluation of the micropump, and carried out the experiment driven by a sine voltage input.

The research illustrates

(1) The structure of the micropump is effective.
(2) The flow 4.5 μl/min~37.8 μl/min can be obtained by changing the frequency.
(3) The proposed micropump is able to make a microflow and is suitable for the use in medical applications and in biotechnology.

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2 Nemat-Nasser S, Hori M. Micromechanics: Overall Properties of Heterogeneous Materials. New York: North-Holland, 1993

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