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A Novel Type of Micropump Using Solenoid Actuator for Biomedical Applications

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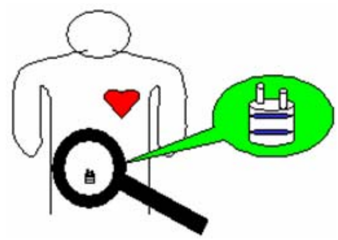
Abstract - **In the medical field and in biotechnology, a new type of micropump that can supply micro liquid flow has urgently been demanded. It is our purpose to develop a novel type of micropump that has the characteristics of flexibility, low voltage input, good response and safe for using in human body. In this paper, we propose a new prototype model of a micropump using solenoid actuator as the servo actuator. This paper describes the new structure and the motion mechanism of a micropump using a solenoid actuator and discusses the possibility of the micropump. This micropump consists of two one-way valves, a pump chamber made of elastic tube, and a casing. The overall size of this micropump prototype is 18mm in diameter and 54mm in length. Characteristic of the micropump is measured. The experimental results indicate that the micropump has the satisfactory responses, and the proposed micropump is able to make a micro flow and is suitable for the use in medical applications and in biotechnology.**

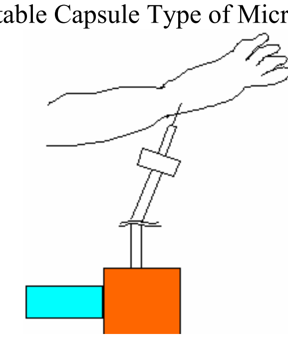
Index terms - Micropump, Micro Flow, Solenoid Actuator, Medical Applications.

I. INTRODUCTION

Intracavity intervention is expected to become increasingly popular in the medical practice, both for diagnosis and for surgery as shown in Fig.1. As we know, many kinds of micro actuator 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 micro machine technologies. In the medical field and in biotechnology, a new type of micro pump that can supply micro liquid flow has urgently been demanded. The micropump 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, SMA actuator and PZT actuator have been reported so far [1]-[7] [13]-[15]. However there are some problems, such as compact structure, slow response, leaking electric current, safety in body and so on. The micropump with supplying micro liquid flow and safety has never been developed so far. It is our purpose to develop a type of micropump 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 micropump using solenoid actuator as the servo actuator. This paper describes the new structure and the motion mechanism of a micropump using a solenoid actuator and discusses the possibility of the micropump. The experimental results indicate that the micropump has the satisfactory responses, and the proposed micropump is able to make a micro flow and is suitable for the use in medical applications and in biotechnology.



(a) Implantable Capsule Type of Micropump



(b) Automatic Medical Fluid Pouring System

Fig. 1 Concept of the Micropump for Medical Practice

II. STRUCTURE OF MICROPUMP

A. Total Structure of the Micropump

Fig.2 shows the basic structure of the developed micropump using a solenoid actuator. This pump consists of a casing, pump diaphragm driven by an installed on its end, and two one-way valves installed on one side of the pump chamber. Solenoid actuators are installed for supplying a large flow range. The photo of the developed micropump is shown in Fig.3.

B. Solenoid Actuator

Development of a small, lightweight actuator is the most difficult challenge for totally implantable micropump because space in the body is limited. We have a deep interest regarding the actuator to obtain the actuation properties in smart structure. Compare to other actuators, such as electrostatic, piezoelectric and magnetostrictive, solenoid actuator has the advantage of high power, large stroke, controllability, safety and large force output.

The solenoid actuator [SDC-0420(4D)] utilized in this work is as shown in Fig. 4. It is known as a smart actuator use for micro devices. It is very easy to work by electrical application with about 4 volts. Working speed and displacement of the solenoid are proportional to the electrical voltage on it. Fig.5 shows the experimental results of solenoid actuator used for micropump.

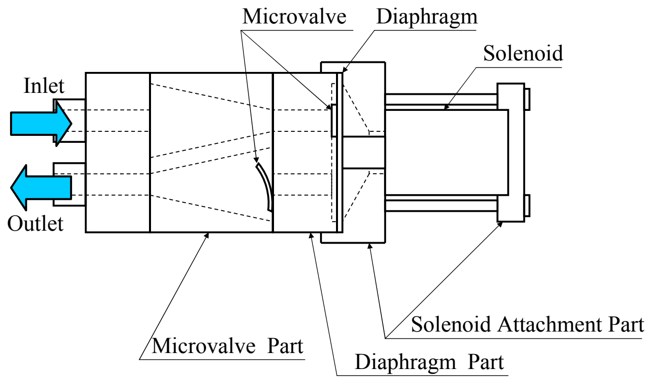
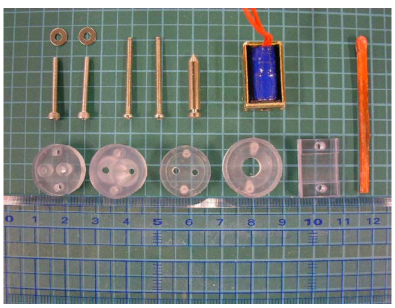
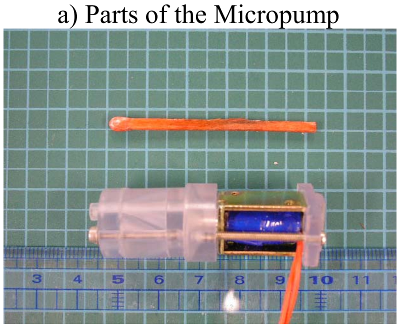


Fig. 2 Total Structure of the Micropump



a) Parts of the Micropump



b) Total Micropump

Fig. 3 View of the Developed Micropump

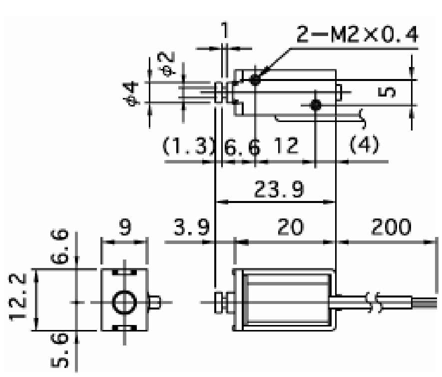


Fig. 4 Specification of the Solenoid Actuator

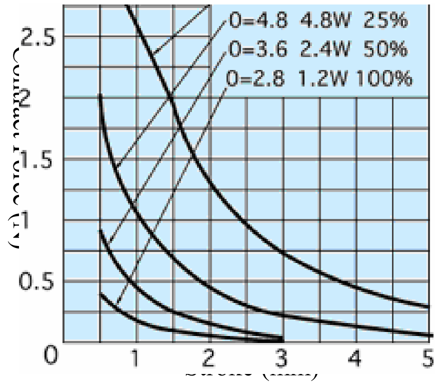


Fig. 5 Response Characteristic of the Solenoid Actuator

III. MOTION MECHANISM OF THE MICROPUMP

The developed micropump consists of two one-way valves (inlet and outlet), a pump chamber made of elastic tube, and a casing. The size and weight of implantable micro devices (micropump) is so important that various investigators have taken various developmental approaches. The development of one-way valve for micropump is very important issue. Up to now, the one-way valves for micropump are all passivity type, so that it is very difficult to realize the compact structure. In this paper, we aimed to solve the problem by using two diffusers in inlet side and in outlet side instead of one-way valve as shown Fig.6. So it enabled us to realize a small and lightweight implantable micropump device. The miniaturization is successful compared with a usual one-way valve as shown in Fig.7. It is partly prevented that the solution flows from the outlet tube into the chamber as shown in Table.1.

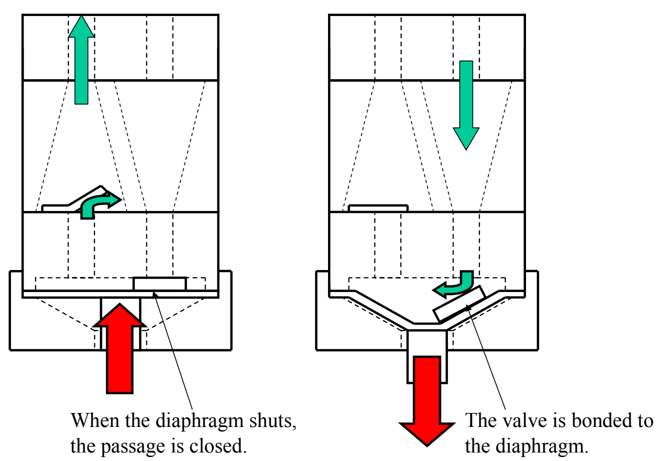


Fig. 6 Mechanism of proposed one-way valves

Table 1 Working Mechanism of the Diffuser

Process	Liquid Flow
Liquid nlet to chamber	$Q_{in} > Q_{out}$
Liquid outlet from chamber	$Q_{in} < Q_{out}$

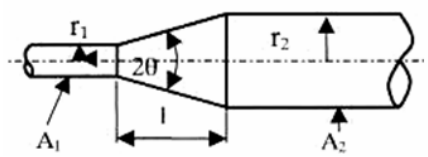
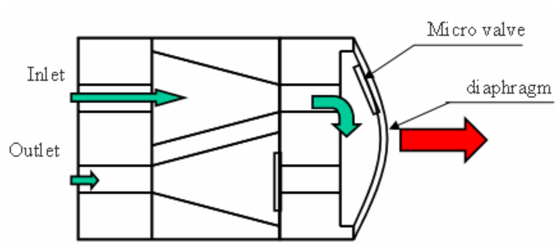
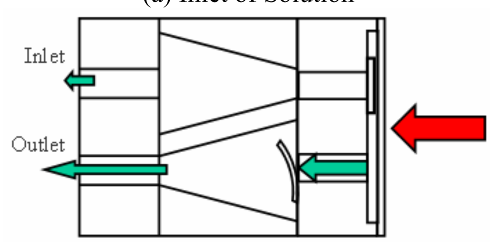


Fig. 7 Diffuser for Micropump



(a) Inlet of Solution



(b) Outlet of Solution

Fig. 8 Mechanism of Micropump Using Solenoid Actuator

The actuating mechanism is as follows shown in Fig.8.

(1) When the solenoid actuator that is fixed on the diaphragm of the pump chamber, is contracted by application of electricity, the volume of the pump chamber increases, resulting the liquid flow from the inlet to the chamber.

(2) By changing the electrical current, it is returned to the original state according to the elastic recovery power of the chamber. So the volume of the pump chamber decreases, resulting in the inflow of liquid from the chamber to the outlet.

(3) The solenoid actuator is put on a pulse voltage; the micropump provides liquid flow from the inlet to the outlet continuously.

IV. Characteristic Measurement

A. Measurement System

The electric voltage set onto solenod actuator can be controlled by a computer. The electrical current is measured by a galvanometer. The contract displacement of the diaphragm is measured by a laser displacement sensor. The volume change of pump chamber can be obtained. Measurement system is shown in Fig.9.

B. Characteristic of the Solenoid Actuator

By using the measurement system as shown in Fig. 9, the following characteristics of the solenoid actuator for micropump is measured. We measured the response characteristic of the actuator by changing the input voltage and by changing the frequency of voltage input. The experimental results are shown in Fig.10. From these experimental results, it is seen that the maximum displacement happens at 50 Hz, which is nearly proportional to the input voltage respectively, and the solenoid actuator is effective for the micropump driven by electrical application.

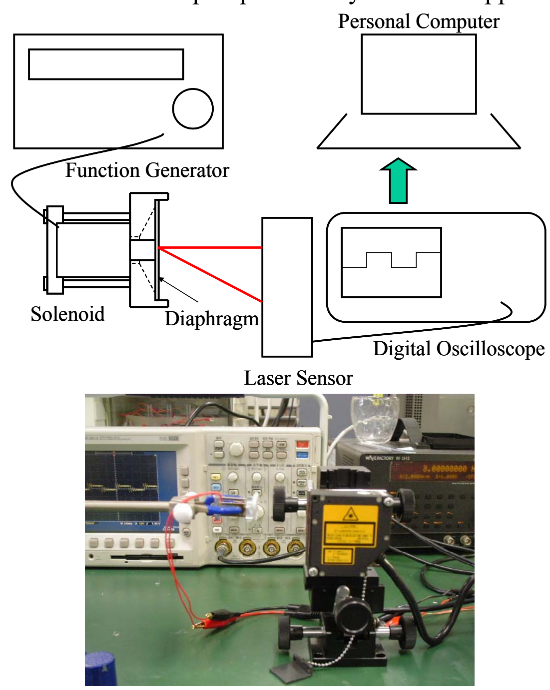


Fig. 9 Measurement System

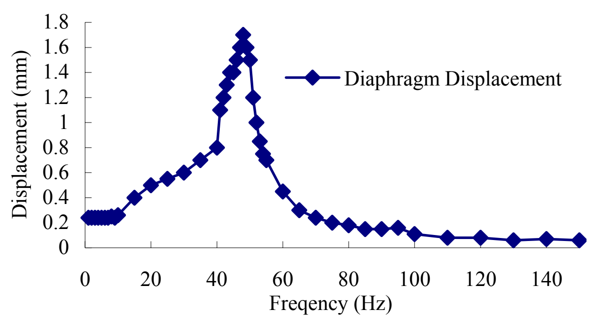


Fig. 10 Displacement Characteristic of the Actuator

C. Diffusers Characteristic

Based on the performance of straight-wall diffusers [10], we designed the diffusers for the micropump. The equation (1) is used to calculate the pressure recovery efficiency of diffuser. Fig.11 shows the diffusers characteristic of the micropump. The parameters as shown in Fig.7 can be obtained.

$$\eta = \frac{p_2 - p_1}{\frac{\rho}{2} U_1^2 \left\{ 1 - \left(\frac{A_1}{A_2} \right)^2 \right\}} \tag{1}$$

Where η is the pressure recovery efficiency of diffuser; ρ is density of fluid; $\boldsymbol{U}$ is the flow velocity; $\boldsymbol{A}$ is the cross-section area; $\boldsymbol{P}$ is the static pressure.

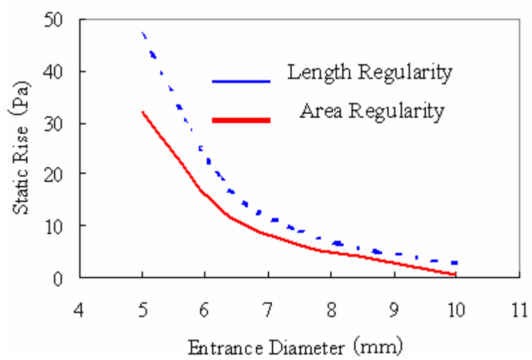


Fig. 11 Diffusers Characteristic of the Micropump

V. Flow Evaluation of Micropump

When micropump is driven by a plus voltage input, it is very important that to evaluate the flow output by changing the frequency of pulse voltage input. In this paper, we present a calculation method of the micropump using solenoid actuator based on the displacement of the diaphragm as shown in Fig. 11(a). In order to obtain the theoretical equations of flow characteristic, the following conditions to the solenoid actuator and diaphragm are assumed.

(1) While the solenoid actuator is driven by a pulse voltage input, the displacement of diaphragm is ***h***, which is approximately a straight line.

(2) The initial diameter of the diaphragm is ***d***, and the diameter of the solenoid is ***d'***.

Based on the above assumptions, the model of flow evaluation is shown in Fig.12. We intend to express the flow output of a cycle ***V*** and flow per second ***Q*** is in terms of diameter ***d***, ***d'***, parameter ***h*** and so on. The following equations (2) - (4) can be obtained.

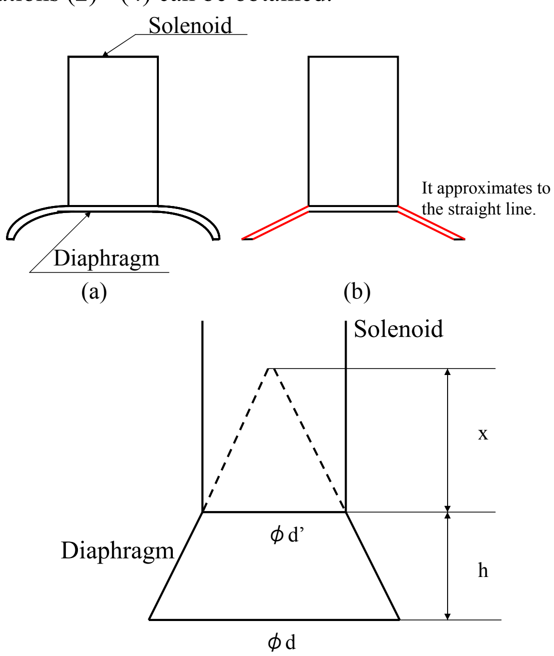


Fig. 12 The Model of Flow Evaluation

$$x = \frac{d'h}{d-d'} \tag{2}$$

$$V = \frac{\pi}{12}\left\{d^2 h + x\left(d^2 - d'^2\right)\right\} \tag{3}$$

$$Q = \frac{\pi f}{12}\left\{d^2 h + \frac{d'h}{d-d'}\left(d^2 - d'^2\right)\right\} \quad \text{(ml/sec)} \tag{4}$$

Where ***f*** is the frequency of a driving pulse voltage input; ***Q*** is the flow per second;

On the basis of equation (4), 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 controlled by changing the frequency of input voltage.

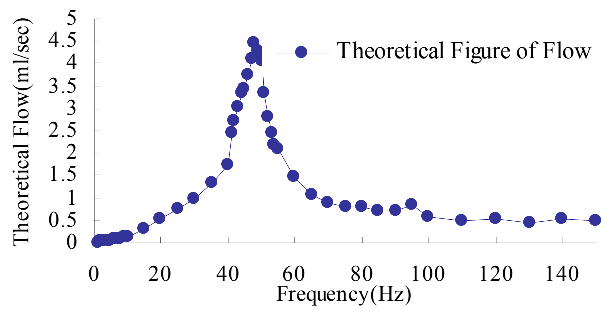


Fig. 13 Calculated Results of the Flow Evaluation (12V)

VI. Prototype Micropump

The prototype of developed micropump using solenoid actuator is shown in Fig.3. The specification of the pump is 18mm in diameter, 54mm in length as shown in Table 2. The micropump is mainly made of acryl material, because the physiological saline is used for the experiments.

Table 2 Specification of Prototype Micropump

Size	54mm*Φ18mm
Material	Body: Acryl Diaphragm: Silicon Rubber
Actuator	Solenoid Actuator
Weight	13.95 g(Including Solenoid Actuator)
Flow	200μl/min. (Rated), 1000μl/min. (Max.)
Power Supply	Electricity (e.g. 6, 0.25A)

On the basis of equation **(4)**, the flow of micropump is calculated by using the experimental maximum displacement. By using the flow measurement system shown in Fig.14, We carried out the experiment of flow measurement in 3 ~ 12 voltage input by changing the frequency from 1Hz to 150Hz. The experimental results and calculation results of flow output of micropump are shown in Fig.15 and Fig.16.

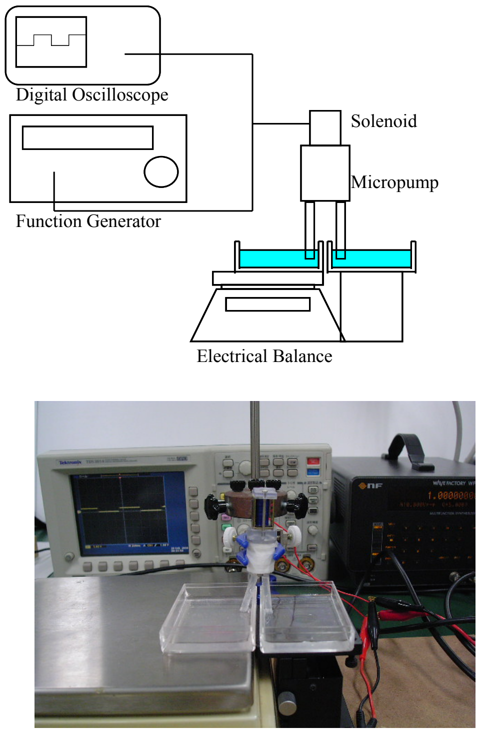


Fig. 14 Measurement System of the Flow Evaluation

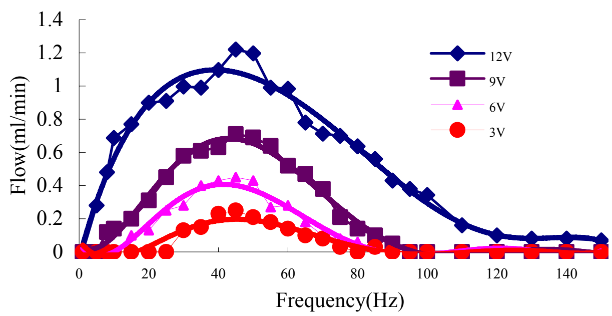


Fig. 15 Experimental Results of the Flow Output

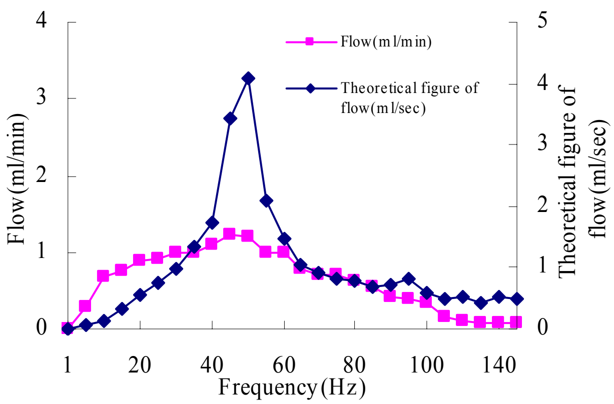


Fig. 16 Comparison of Flow of the Micropump (12V)

The experimental results indicate that the micropump has the satisfactory responses, the flow 200μl/min. ~ 1000μl/min. at 50Hz can be obtained by changing the frequency of input voltage. Also the developed micropump can obtain the large range of output flow by changing input voltage.

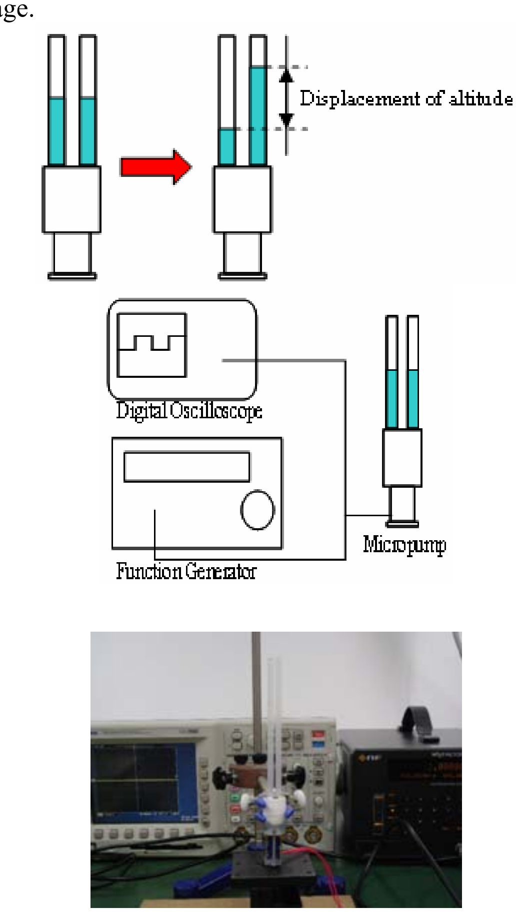


Fig. 17 Measurement System of the Pressure Evaluation

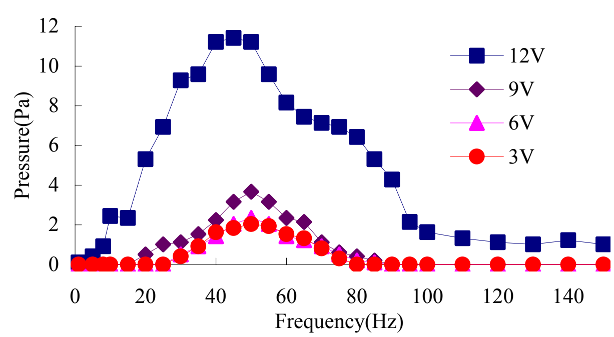


Fig. 18 Experimental Results of the Output Pressure

In the other hand, we also measured the output pressure of the micropump using the pressure measurement system shown in Fig.17 by changing the input voltage. The experimental results of output pressure of micropump are shown in Fig.18. The experimental results indicate that the micropump has the satisfactory responses, the output pressure 2Pa ~ 11Pa at 50Hz can be obtained by changing the frequency of input voltage and changing input voltage. Also the maximum output pressures appear at 50 Hz. This is the significant advantage of the micropump. It can be widely used for various applications such as in medical applications and so on.

VII. Conclusions

In this paper, we propose a new prototype model of a micropump using a solenoid actuator as the servo actuator. We also discussed the structure, characteristic measurement, flow evaluation and output pressure of the micropump, and carried out the experiment driven by pulse voltage inputs.

The research illustrates

(1) The structure of the micropump is effective.
(2) The micropump has the satisfactory responses.
(3) The flow 200µl/min. ~ 1000µl/min. and output pressure 2Pa ~ 11Pa can be obtained by changing the frequency of input voltage and changing input voltage.
(4) The proposed micropump is able to make a large range of micro flow and is suitable for the use in medical applications and in biotechnology.

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