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A flow rate on-line monitoring method for piezoelectric pump based on self-sensing circuit

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Abstract This paper presents a new flow rate monitoring method for a piezoelectric micropump based on a self-sensing circuit. Utilizing the voltage generated by the secondary direct piezoelectric effect as the sensing voltage, a soft sensor of the piezoelectric actuator can be implemented onto the piezoelectric micropump. A bridge-type circuit is proposed as the self-sensing circuit, the piezoelectric micropump is fabricated with a circular piezoelectric actuator, the characteristics of the self-sensing voltage and the flow rate are experimentally investigated under different excitation voltages and frequencies. The results show that the method can accurately determine optimal frequency of the micropump (100 Hz, 280 Hz), and for a fixed frequency of 100 Hz and a voltage range of 50-180 V, the correlation between the self-sensing voltage and the flow rate is 0.9732. As a result, the method demonstrated in this paper allows precise monitoring of the flow rate of the piezoelectric micropump without using external sensors.

1. Introduction

Piezoelectric micropumps have become an important microfluidic component that is widely used in microfluidic systems due to its simple structure, small size and fast mechanical response time. Piezoelectric micropump research started in the 1970s [1], and how to accurately control the flow rate during the excitation process of the piezoelectric micropumps is a key matter investigated in microfluidic systems [2-5]. The first step of flow rate control is to monitor the flow rate of the piezoelectric micropumps, and various methods have been developed [6-15].

The traditional method isto integrate sensors onto piezoelectric micropumps [6-8]. Nguyen et al. integrated a thermal flow rate sensor onto a flexural plate wave (FPW) pump to measure the small volume flow rates in the device [6]. Fouillet et al. used a built-in differential pressure sensor to monitor the flow rate, and used a Wheatstone bridge to ensure the reliability of this method [7]. To realize a high integration device for the driving fluid and monitoring status, Fuchs et al. enabled the MEMS technology by directly arranging the integrated sensor on the silicon membranes [8]. In addition, the method to realize the self-sensing piezoelectric micropump based on space-division multiplexing (SDM) is also an attractive topic [9-13]. The self-sensing piezoelectric micropump based on SDM proposed by Zhang et al., dividing the electrode of the piezoelectric actuator into two parts (an excitation unit and a sensing unit), can realize the function [9, 10]. The self-sensing piezoelectric pump developed by using piezoelectric bimorphs can complete the task of monitoring flow rates and back pressures [11, 12]. In addition, the method of time-phase shift [14] and the method of establishing the electrical model of the piezoelectric micropumps [15] can also realize the flow rate monitoring function of piezoelectric micropumps.

However, piezoelectric materials, as smart materials, can be used simultaneously as an actuator and a sensor by themselves. Self-sensing actuation (SSA) is a technology that employs the induced voltage by the secondary effect of PEA to estimate its displacement [16]. The self-sensing circuit can extract the induced voltage in two forms by which it is classified: bridge decoupling [17-20] and charge sensing [21-23]. The bridge decoupling method, which was first studied and documented by Dosch et al., can measure either strain or time rate of strain in piezoelectric actuators [17]. In recent years, this initial bridge decoupling method has been developed into various forms and has been employed in many fields, such as hard-disk drives [18, 24, 25], piezoelectric printing heads [26], and vibration suppression of piezoelectric beams [27, 28].

This paper draws on the principle of self-sensing actuation technology to design a self-sensing circuit for application in the piezoelectric micropump drive system, which realizes self-detection of the output flow rate during driving and realizes the collocation of the actuator and the sensor. In addition, the method proposed in this paper does not need to modify the structure of the piezoelectric micropump to install the microsensor, but only to adopt a decoupling-bridge type circuit to realize the driving and sensing function. Compared with the SDM method as mentioned above, this method employs both the inverse piezoelectric effect and the direct piezoelectric effect in the same area of the piezoelectric actuator, and the obtained sensing voltage can more precisely represent the state of the piezoelectric micropump. The excitation frequency and the excitation voltage characteristics of the micropump were experimentally investigated. The results show that the combination of the traditional piezoelectric micropump and the self-sensing circuit can realize the self-sensing function of the flow rate. It also provides new ideas for the design of the piezoelectric micropump online flow-rate monitoring method and the closed-loop control system.

2. Principle and design

2.1 Analysis of secondary direct piezoelectric effect

As one kind of smart material, the piezoelectric materials have both direct and inverse piezoelectric effects. And piezoelectric sensors can be based on the direct piezoelectric effect, whereas the piezoelectric actuators on the inverse piezoelectric effect. At the same time, the direct piezoelectric effect and the inverse piezoelectric effect are not repulsive, but they can occur simultaneously. As shown in Fig. 1, the mechanism of the secondary direct piezoelectric effect is explained on the electromechanical coupling model. The excitation voltage applied to the piezoelectric material in the form of charge $Q(t)$ causes deformation of the material, the amount of deformation is $X(t)$, and the transduced force that causes the material to deform is $F(t)$, which defines the first inverse piezoelectric effect. The deformation $X(t)$ produced by the first inverse piezoelectric effect will induce charge $q(t)$ in the piezoelectric material, which appears on the surface of the piezoelectric material in the form of a voltage $V_s(t)$ and defines the secondary direct piezoelectric effect. The electrical equations can be written as follows:

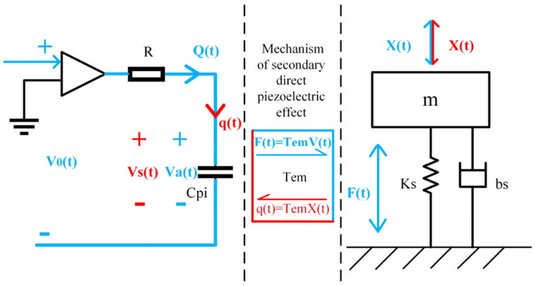


Fig. 1. The generation mechanism of the secondary direct piezoelectric effect.

$$R\dot{Q}(t)+V_a(t)=V_0(t)\,, \tag{1}$$

$$V_a(t)=\frac{Q(t)}{C_{pi}}\,, \tag{2}$$

$$F(t)=T_{em}V_a(t)\,, \tag{3}$$

$$m\ddot{X}(t)+b_s\dot{X}(t)+k_sX(t)=F(t)\,, \tag{4}$$

$$q(t)=T_{em}X(\mathrm{t}), \tag{5}$$

$$V_s(t)=\frac{q(t)}{C_{pi}} \tag{6}$$

where, $V_0(t)$ is the input excitation voltage, $V_a(t)$ is the excitation voltage imposed on the piezoelectric material T_{em} represents the piezoelectric effect, R is the equivalent resistance in the circuit, C_{pi} is the electrical equivalent capacitance of piezoelectric materials; m, b_s, and k_s are, respectively, the equivalent mass, damping coefficient and stiffness in mechanical model.

Eq. (5) into Eq. (6), Eq. (7) will be obtained:

$$V_s(t)=\frac{T_{em}X(t)}{C_{pi}}\,. \tag{7}$$

Therefore, if the secondary direct piezoelectric effect is considered, the voltage that can be detected on the surface of piezoelectric material is V_{pi}:

$$V_{pi}=V_s(t)+V_a(\mathrm{t})=\frac{T_{em}X(\mathrm{t})+Q(t)}{C_{pi}}\,. \tag{8}$$

The secondary direct piezoelectric effect in the piezoelectric transducer is similar to the back electromotive force in the motor [29]. In fact, multiple effects exist in all bi-directional transducers. In previous research on piezoelectric materials, sensors or actuators based on the principle of primary effects are mostly studied, only few are focused on the secondary or multiple piezoelectric effects. According to the cross-coupling

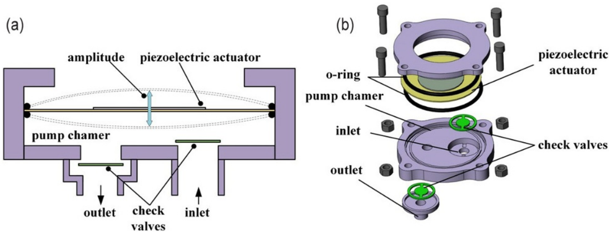


Fig. 2. Structural configuration of piezoelectric micropump: (a) cross-section schematic; (b) the 3-D assembly schematic.

characteristic, the real-time state of a piezoelectric transducer can be derived without any external sensors, which is a valuable alternative to the traditional hardware sensor and also a reliable scheme to boost realization of the MEMS technology of piezoelectric materials.

2.2 Theoretical analysis of the relationship between flow rate and self-sensing voltage

The structure of a typical valved piezoelectric micropump, shown as Fig. 2, includes an inlet, outlet, piezoelectric actuator, check valves, and pump chamber. An alternating current voltage is used to reciprocate the piezoelectric vibrator, thereby increasing or decreasing the chamber. The flow direction of the fluid is controlled by the inlet and outlet valves.

When a piezoelectric actuator in the piezoelectric pump is driven by the excitation voltage, bending deformation occurs, which leads to a change of the pump cavity volume and directional motion of the fluid. In this process, the induced voltage generated by the secondary direct piezoelectric effect can reflect the working state of the piezoelectric pump. Based on this principle, the sensor-actuator function in the piezoelectric pump can be realized. The calculation equation of the sensing voltage U is as follows [10]:

$$U = \frac{3d_{31}h_{31}d^2V}{8t^2} \tag{9}$$

where d_{31} is the piezoelectric strain coefficient; h_{31} is the piezoelectric stiffness coefficient. V is the excitation voltage; d is the diameter of the piezoelectric actuator; t is the thickness of the piezoelectric actuator. The displacement calculation of the center point of the piezoelectric actuator in the piezoelectric micropump is shown below [1]:

$$\delta = \frac{3}{8}\frac{g_{31}\varepsilon_{33}^T d^2V}{t^2} \tag{10}$$

where, g_{31} is the appropriate piezoelectric and ε_{33}^T is the dielectric coefficients. The relationship between them can be expressed as follows:

$$d_{31} = g_{31}\varepsilon_{33}^T . \tag{11}$$

Eq. (11) into Eq. (9), Eq. (12) will be obtained [10]:

$$U = \frac{3g_{31}\varepsilon_{33}^T h_{31}d^2V}{8t^2} = h_{31}\delta . \tag{12}$$

It is known that when an AC signal excites a piezoelectric micropump, the deformation of the pump cavity is calculated as follows [30]:

$$\Delta V = \delta\frac{\pi d^2}{8} . \tag{13}$$

After substituting Eq. (13) into Eq. (12), the relationship between the sensing voltage and the deformation of the pump cavity will be obtained as Eq. (14).

$$U = \frac{8\Delta V h_{31}}{\pi d^2} . \tag{14}$$

The calculation of the flow rate is as follows [31]:

$$Q' = 2\eta\Delta V f \tag{15}$$

where, η is the working efficiency of the piezoelectric micropump; f is the frequency of the excitation signal. After substituting Eq. (15) into Eq. (14), the relation between flow rate and sensing voltage signal is as follows:

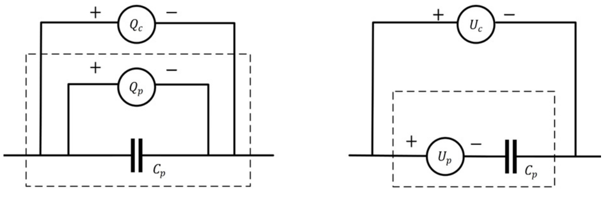
$$U = \frac{4Q' h_{31}}{\pi d^2\eta f} . \tag{16}$$

This equation establishes a relationship between the sensing voltage and the flow rate of the piezoelectric micropump, by which, once the sensing voltage is extracted effectively, the flow rate of the micropump can be successfully measured and predicted.

2.3 Bridge circuit for rate self-sensing

When the piezoelectric actuator in the piezoelectric micropump is used as a sensor-actuator, due to the dielectric nature of the piezoelectric material, the piezoelectric actuator can be equal to the two electrical models as shown in Fig. 3. When employing a charge source to drive the piezoelectric pump, the equivalent model is shown as Fig. 3(a). Under this condition the piezoelectric actuator is composed of a charge source and a capacitor connected in parallel. When the piezoelectric pump is excited by a voltage source, the equivalent model is shown as Fig. 3(b), and the piezoelectric actuator is composed of a voltage source and a capacitor connected in series.

Unfortunately, regardless of the charge drive or the voltage drive, the equivalent charge source Q_p and voltage source U_P .



(a)

(b)

Fig. 3. Equivalent electrical model for the piezoelectric actuator: (a) charge source equivalent model; (b) voltage source equivalent model.

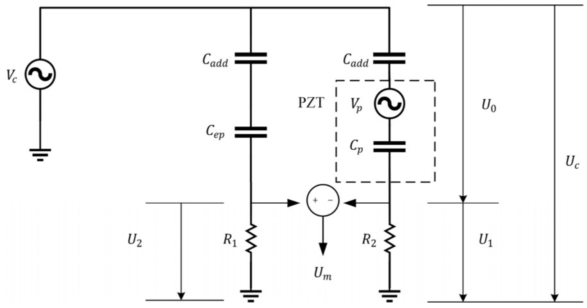


Fig. 4. Self-sensing strain rate bridge.

Generated by the secondary direct piezoelectric effect is mixed in the excitation voltage, and the sensing voltage cannot be detected directly. To truly collocate the sensor and actuator together, the excitation charge (voltage) must be separated from the sensed charge (voltage) by decoupling. Many methods have been proposed for decoupling the excitation voltage and the self-sensing voltage of piezoelectric materials. The decoupling method introduced in this article is based on the bridge-circuit decoupling method proposed by Dosch et al. [17], and the topology of the circuit is shown in Fig. 4.

In the bridge circuit, the piezoelectric actuator in the piezoelectric micropump is equal to a capacitor C_p connected in series with a voltage source V_p, and with a resistor R_2 in series to form a bridge arm. C_{ep} and R_1 are connected in series to form another bridge arm, C_{ep} is a capacitor that matches the PZT and its matching accuracy determines the performance of the bridge to extract the sensing voltage [27]. The additional capacitor C_{add} on the two bridge arms is to improve the stability of the circuit system [32]. As long as the parameters on the two bridge arms are matched, the self-sensing voltage that contains the flow rate information of the piezoelectric micropump can be obtained.

The voltage U_1 is :

$$U_1 = R_2 \frac{\left(V_p + V_c\right)}{Z} = \frac{R_2 C_p^{'} S}{1 + R_2 C_p^{'} s}\left(V_p\left(s\right) + V_c\left(s\right)\right). \tag{17}$$

The voltage U_2 is :

$$U_2 = R_1 \frac{V_c}{Z} = \frac{R_1 C_{ep}^{'} S}{1 + R_1 C_{ep}^{'} S} V_c\left(s\right) \tag{18}$$

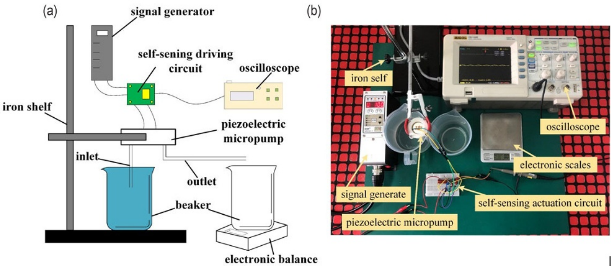


Fig. 5. Model schematic and apparatus photograph of the testing experimental: (a) model schematic; (b) apparatus photograph of the experimental.

where, $C_p^{'} = C_p // C_{add}$, $C_{ep}^{'} = C_{ep} // C_{add}$.

The expression of the extracted self-sensing voltage U_m in terms of Laplace transform variables is:

$$U_m s = U_1\left(s\right) - U_2\left(s\right) = \frac{R_2 C_p^{'} s}{1 + R_2 C_p^{'} s} V_p s + \left[\frac{R_2 C_p^{'} S}{1 + R_2 C_p^{'} S} \frac{R_1 C_{ep}^{'} S}{1 + R_1 C_{ep}^{'} S}\right] V_C\left(s\right) \cdot \tag{19}$$

When $C_p^{'} R_2 = C_{ep}^{'} R_1$, Eq. (19) can be rewritten as follows:

$$U_m\left(S\right) = \frac{R_2 C_p^{'} s}{1 + R_2 C_p^{'} s} V_p\left(s\right). \tag{20}$$

According to Ref. [17], when $\omega \ll 1/R_2 C_p^{'}$, Eq. (20) can be written as follows:

$$U_m s = V_p\left(s\right). \tag{21}$$

The extraction voltage $U_m\left(s\right)$ of this circuit can reflect the transformation rate of the sensing voltage. Combined with Eq. (16), it can be known that the extraction voltage of this circuit reflects the flow rate of the piezoelectric micropump.

3. Experimental setup

The feasibility of the piezoelectric pump combined with the self-sensing circuit needs to be verified through experiments, and the relationship between the sensing voltage and the flow rate needs to be measured. The testing experiment diagram is shown as Fig. 5. The testing system includes a signal generator, a self-sensing circuit, an oscilloscope, a piezoelectric micropump, an electronic scale, and two beakers. The piezoelectric micropump is fixed on the iron shelf. The signal generator (CUH, SDVC40-S) generates a sinusoidal voltage to excite the piezoelectric micropump. The self-sensing circuit is implemented on a breadboard as shown in Fig. 5, which is used to extract the sensing voltage of the piezoelectric actuator. The digital oscilloscope (RIGOL, DS1102E) is used to observe the sensing voltage. The electronic scale is used to measure the flow rate of the piezoelectric pumps.

Fig. 6 displays the schematic of the self-sensing piezoelectric

Table 1. Values of the circuit components.

Component parameters	Value
$C_{ep} = C_p$	24 nF
C_{add}	100 nF
$R_1 = R_2$	10 KΩ

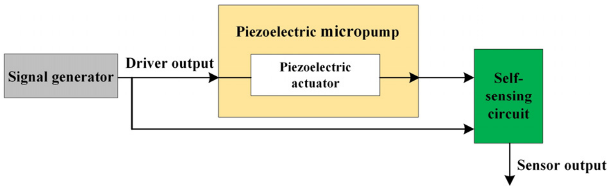


Fig. 6. Diagram of piezoelectric pump self-sensing system implemented.

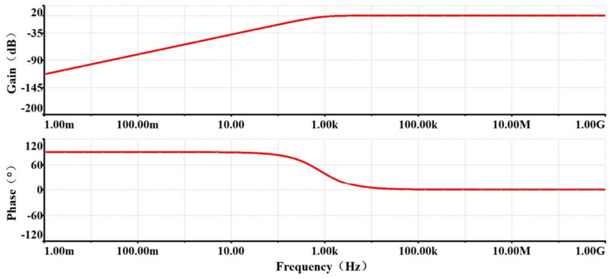


Fig. 7. Frequency responses of self-sensing strain rate bridge.

micropump system with the self-sensing circuit. The self-sensing circuit as the most important part of the entire system extracts the self-sensing voltage and outputs the voltage to the oscilloscope. The sensing voltage can be used to characterize the flow rate theoretically when the piezoelectric pump is working.

From the perspective of the circuit diagram, each bridge arm is equivalent to a high-pass filter model. To ensure the piezoelectric micropump is excited at the normal state when completing the function of the self-sensing actuation, each module of the system should be well set. The micropump is a single chamber pump with a piezoelectric actuator, the work frequency of the micropump is about dozens of hertz to a few hundred hertz, and work voltage is below 200 volts. Beyond this range of voltage and frequency will depolarize the piezoelectric material and affect the service life of the piezoelectric actuator in the micropump. The static capacitance of the piezoelectric material is approximately 24 nF as measured by a multimeter. Considering that the excitation voltage of the generator used is 0 to 220 V and the frequency is within 40 Hz to 400 Hz, most of the excitation voltage should be applied to the piezoelectric micropump, and each bridge arm should be set in a high-pass filtering state. The cut-off frequency of the equivalent high-pass filter must be greater than 400 Hz. The settings of the parameters of the components are shown in Table 1. As shown in Fig. 7, the cut-off frequency of the self-sensing circuit is 822.9 Hz, which is higher than the frequency of the generator.

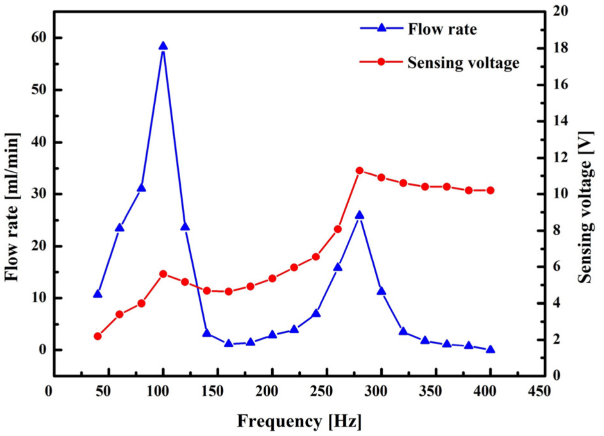


Fig. 8. The relationship between flow rate and self-sensing voltage as a function of excitation frequency at a fixed excitation voltage of 70 V_{rms}.

4. Experimental results and discussion

To demonstrate the feasibility of the self-sensing circuit for the piezoelectric micropump, the excitation frequency and voltage as the important performance factors of the piezoelectric pump should be tested. The experiments on the frequency characteristics of the self-sensing micropump are first done at the given voltage of 70 V_{rms}. To ensure the accuracy of the experiments, each group of the experiments was repeated three times to reduce the experimental error.

Fig. 8 shows the experimental results of the output flow rate and the sensing voltage obtained by changing the frequency under a fixed voltage of 70 V_{rms}. As shown in Fig. 8, the curves of the sensing voltage and the flow rate show a correlation. Within the frequency range of 40 Hz to 400 Hz, the peak points of the flow rate and the sensing voltage both appear at 100 Hz and 280 Hz. At 100 Hz, both reach the first peak point, the flow rate is 58.33 ml/min, and the sensing voltage is 5.6 V_{pp}. At this time, the working of the piezoelectric micropump is at the best state; the piezoelectric actuator of the piezoelectric micropump generates the largest deformation, and the sensing voltage caused by the secondary direct piezoelectric effects also increases to the maximum value. Continuing to increase the frequency, both reach the second peak point at 280 Hz. At this time, the flow rate is 25.87 ml/min and the sensing voltage is 11.3 V_{pp}. Compared with the first peak point, the flow rate of the second peak point has decreased, but the sensing voltage has increased. This is because these two peak points (100 Hz, 280 Hz) are all the best working points of the piezoelectric pump, but at 100 Hz the working state of the micropump is better than 280 Hz, which we can estimate that 100 Hz is the optimal operating frequency of the pump. Therefore, the general trend of the flow rate is downward. On the other hand, the stability of the bridge circuit will reduce under the condition of large voltage and high frequency, which will cause the excitation voltage to flee into the sensing voltage and pollute the sensing voltage. Therefore, the general trend of the sensing voltage is upward. Because the open and close of the valves

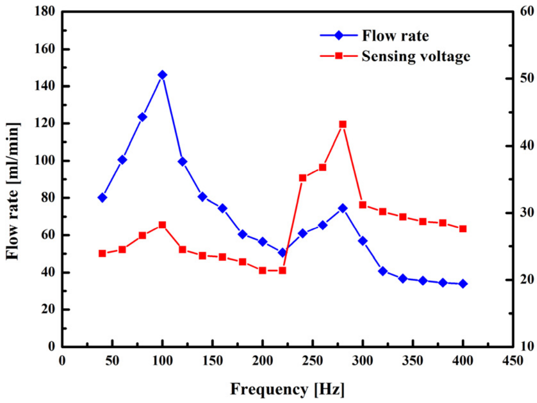


Fig. 9. The relationship between flow rate and self-sensing voltage as a function of excitation frequency at a fixed excitation voltage of 140 V_{rms}.

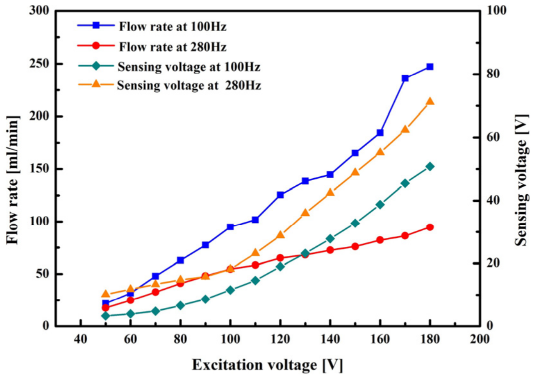


Fig. 10. The relationship between flow rate and sensing voltage and excitation voltage at the frequencies of 100 Hz and 280 Hz.

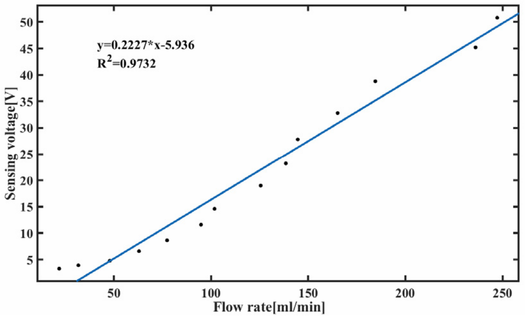


Fig. 11. The relationship between flow rate and sensing voltage as a linear function of excitation voltage.

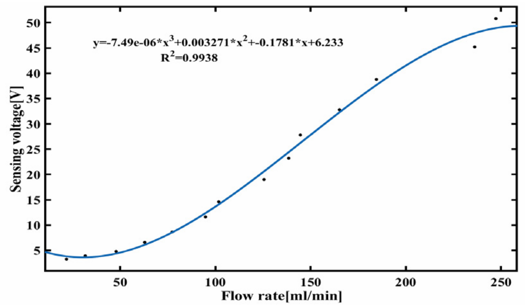


Fig. 12. The relationship between flow rate and sensing voltage as a cubic function of excitation voltage.

always lag behind the actuator's vibration, the flowrate and the excitation frequency are not in a linear relationship; there is the frequency at which the flow rate can reach the max, the optimal excitation frequency for the piezoelectric micropump can be obtained through experiments. These frequency character experiments show that the sensing voltage and the flowrate have the same trend and peak points; the best working frequency of the micropump can be determined by monitoring the sensing voltage.

In the examples of the flow rate self-detection of the piezoelectric micropump realized by SDM and the bimorph transducer, the peak points of the self-sensing voltage and flow rate obtained from the frequency characteristic experiments are lagging or leading [9, 11-13]. This is because the actuation area and the sensing area of the two methods are different; the sensing voltage cannot truly reflect the working state of the piezoelectric micropump. The bridge type circuit proposed in this paper to extract the sensing voltage in the entire piezoelectric actuator truly realizes the collocation of the sensor and the actuator; the sensing voltage can represent the state of the entire actuation area. Therefore, as shown in Fig. 8, in the frequency character curves, the peak point of the self-sensing voltage and the flow rate perfectly fit, which is better than the first two methods.

In the same way, the relationship between flowrate and self-sensing voltage as a function of excitation frequency at a fixed excitation voltage of 140 V_{rms} is obtained, as shown in Fig. 9. The shapes of the flow curve and sensing voltage curve in Fig. 9 are almost similar to the two in Fig. 8. And the optimal operating frequencies are also the same, which further proves the optimal operating frequencies of the micropump are 100 Hz and 280 Hz. To study the excitation voltage character of the self-sensing micropump system, the experiment of the excitation voltage was conducted at the optimal excitation frequencies of 100 Hz and 280 Hz. As shown in Fig. 10, when the excitation voltage is changed at the fixed frequency of 100 Hz, the sensing voltage and the flow rate have a similar changing trend. At 280 Hz, both of them show an upward trend with the increase of the excitation voltage, but their linearity is lower than that of the frequency fixed at 100 Hz due to the decrease of the stability of the bridge circuit.

We selected the curve of the sensing voltage and the flow rate obtained by changing the voltage at a fixed frequency at 100 Hz for fitting. From Ref. [1], it can be known that the relationship between the sensing voltage and the flow rate should be a standard linear function. We used the least-squares method to linearly fit these two variables, as shown in Fig. 11; the correlation coefficient is 0.9732, which is better than the method based on SDM 0.9716 [11], indicating that the self-sensing voltage obtained in this way can monitor the flow rate well. The function curve fitted with the cubic function is shown in Fig. 12. The correlation coefficient is 0.9938, which can better represent the relationship between the two. Ideally, it should

Table 2. Various liquid self-sensing detections for microfluidic piezoelectric pump.

Reference	Detection method	The relationship between sensing voltage and flow rate	Whether predict the peak point accurately
Zhang et al. [9] (2013)	SDM	Parabolic fitting ($R^2 = 0.9975$)	No
Zhang et al. [12] (2016)	Bimorph transducer	Linear fitting ($R^2 = 0.971$)	No
Chen et al. [11] (2019)	Bimorph transducer	Linear fitting ($R^2 = 0.9716$)	No
This work	Self-sensing circuit	Linear fitting ($R^2 = 0.9732$)	Yes

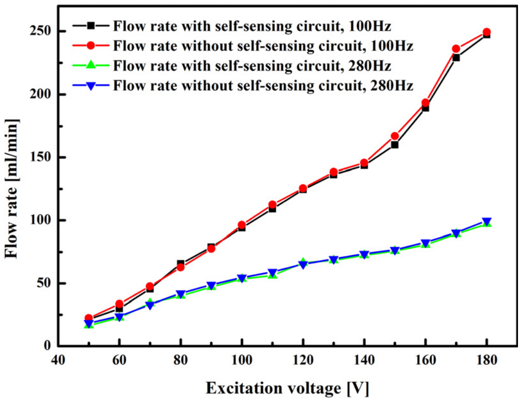


Fig. 13. The flow rate at the frequencies of 100 Hz and 280 Hz with self-sensing circuit and no self-sensing circuit.

be a linear relationship in theory; however, the piezoelectric actuator does not have enough deflection to make the piezoelectric micropump work normally at a low voltage. At a higher voltage, the stability of the self-sensing circuit decreases, which will cause the sensing voltage to be impure. These two reasons lead to a non-linear relation between the flow rate and the sensing voltage. Only in the middle section will there approximatively be a certain linear relationship.

From Table 2, the sensing voltage obtained by using the space division multiplexing (SDM) is in parabolic relationship with the flowrate [9]; the correlation coefficient, R^2 , is 0.9975. The methods realized by bimorph transducer were adopted by Zhang [12] and Chen et al. [11]; the correlation coefficients are respectively, 0.971 and 0.9716 in a linear relationship. The linear relationship states the flowrate could be well reflected by sensing voltage. Because the method proposed in this article is based on the secondary direct piezoelectric effects, the sensing voltage can represent the state of the whole piezoelectric actuator. This method not only has higher correlation coefficients, but also has the ability to determine the optimal excitation frequency points accurately.

From the above experiments the relationship between the sensing voltage and the flow rate is evident. Nevertheless, it is important to show that the real flow rate of the pump is not affected as a result of the application of the self-sensing scheme. In Fig. 13, the flow rate is depicted at two given frequencies, which we have considered in our experiments, from which we can see that the flow rate does not show significant difference with or without the self-sensing circuit.

It can be seen from Figs. 8 to 13 that the sensing voltage obtained by the self-sensing circuit can detect the best operation frequency of the piezoelectric micropump, and can reflect the variation of the flow rate at a certain frequency. Although the sensing voltage and the flow rate are physical quantities of different dimensions, they can reflect the changing trend of the flow rate in general. This paper proves the feasibility of employing the self-sensing circuit to measure the flow rate of the piezoelectric micropump, both theoretically and experimentally, and this kind of soft-sensor monitoring form is suitable for the flow rate measurement of the piezoelectric micropump, which thus provides a new way to realize the closed-loop control or precise flow rate measurement of piezoelectric micropumps.

5. Conclusion

This paper proposes a precise flow rate measurement method for piezoelectric micropumps based on the self-sensing circuit, which can complete the self-detection function of the output flow rate without using external sensors. The symmetrical bridge-type self-sensing circuit is used to excite the micropump on one of the bridge arms, and the other bridge arm has a symmetrical relationship with its constituent circuit. When the bridge circuit reaches a balanced state, a differential voltage is obtained that contains the flow rate information generated by the secondary direct piezoelectric effect. The self-sensing circuit is built on a breadboard by connecting a signal generator to directly drive the piezoelectric micropump, and the flow rate self-detection function of the ordinary piezoelectric micropump is realized. In this paper, a traditional valved piezoelectric pump is used to test the characteristics of the self-sensing system through experiments with water as the working fluid. The experiments show that the changing trend of the self-sensing voltage and the flow rate is similar. By monitoring the self-sensing voltage, the best working frequency of the piezoelectric micropump can be identified, and at a given frequency, the obtained self-sensing voltage by changing the excitation voltage amplitude shows a good consistency with the changing trend of the flow rate. The method proposed in this paper employs self-sensing actuation technology in the piezoelectric micropump and precisely realizes the collocation of the sensor and the actuator in the piezoelectric micropump. This kind of soft sensor can measure the flow rate of the piezoelectric pump without any external sensors, with accuracy that is better than the previous methods. Therefore, this article provides a new method and approach for the flow rate monitoring of piezoelectric micropumps, and can be used as a reference for future research in this field.

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