



A MEMS-Based Piezoelectric Pump with a Low Frequency and High Flow

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Abstract. This paper mainly presents a piezoelectric pump based on a single piezoelectric vibrator under MEMS technology. The piezoelectric vibrator of the piezoelectric pump is made by MEMS technology, and the pump body is completed by 3D printing. Driven by a low-frequency AC voltage of 220 V 50 Hz, the center displacement of the piezoelectric vibrator of the pump can reach 136 μm with high output characteristic. Finally, the piezoelectric pump was used to perform a cooling test on the heating sheet PTC under the condition of 26 °C. It was found that the temperature of the PTC could be reduced by about 20 °C under the condition of the maximum output flow of 159 ml/min. Therefore, the piezoelectric pump has important practical significance in many aspects such as micro flow control and computer CPU cooling.

Keywords: Piezoelectric pump · MEMS · Piezoelectric vibrator

1 Introduction

With the gradual deepening of piezoelectric research, the use of piezoelectric elements as piezoelectric driving mechanisms for micro-pumps has developed rapidly [1–5]. When the inverse piezoelectric effect of the piezoelectric element is used, the piezoelectric material can realize the conversion from electrical energy to mechanical energy without a transmission mechanism [6]. In addition, the driving mechanism has a fast response speed and is easy to drive a small mechanism. Therefore, the application research of piezoelectric elements in micro and small machinery and precision machinery has become a current research hotspot.

In this paper, it proposes a piezoelectric pump driven by a single piezoelectric vibrator based on MEMS technology. The pump combines PZT and beryllium bronze with conductive adhesive in a concentric circle to form a piezoelectric vibrator. The piezoelectric pump has a good output by inputting alternating current with a suitable frequency and has a certain practical value.

2 Structure and Principle

The structure diagram of the piezoelectric pump designed in this paper is shown in Fig. 1(a). It can be seen from the figure that the piezoelectric pump is mainly composed of a pump body, a pump cover, a piezoelectric vibrator, an inlet and outlet valve, a fastening screw, and a diaphragm. The pump cover and the pump body are clamped with fastening screws to play a role of fixing the piezoelectric vibrator. At the same time, in order to prevent the water in the pump cavity from leaking to the surface of the piezoelectric vibrator when the piezoelectric pump is running, the bottom surface of the piezoelectric vibrator is added a waterproof diaphragm plays a sealing role. The inlet valve and outlet valve in Fig. 1(a) communicate with the outside water inlet and outlet, and its function is to form a periodic enclosed space together with the piezoelectric vibrator to complete the pumping process.

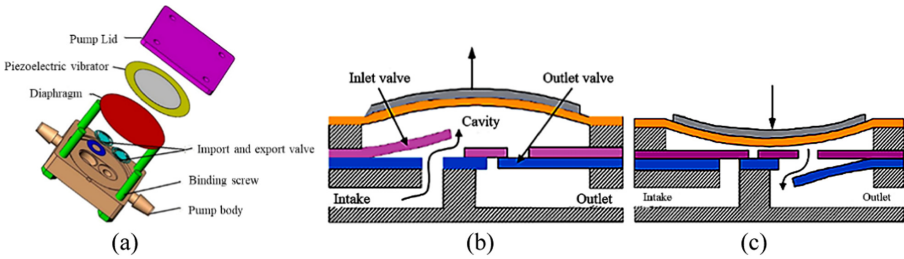


Fig. 1. Piezoelectric pump principle structure diagram (a) structure diagram (b) piezoelectric pump suction (c) piezoelectric pump drainage.

As shown in Fig. 1(b)(c), it is a schematic diagram of the device structure. The working principle of the device is that under the action of alternating voltage, the piezoelectric vibrator is bent up and down to form a cavity volume and pressure changes in conjunction with the opening and closing of the one-way valve, thereby realizing one-way flow of fluid in the whole process. When the piezoelectric vibrator is bent upward and deformed, the volume of the cavity increases and the pressure is lower than the atmospheric pressure, the inlet valve is pushed open, and the liquid is sucked into the cavity, as shown in Fig. 1(b). When the piezoelectric vibrator bends and deforms downward, the piezoelectric vibrator presses the liquid to open the outlet valve, the inlet valve is in a closed state and the liquid is discharged from the outlet, as shown in Fig. 1(c).

3 Simulation Analysis

The piezoelectric pump can work normally depends on normally bending and deforming of the piezoelectric vibrator. Therefore, this paper uses ANSYS software to simulate and analyze the natural frequency and vibration mode of the piezoelectric vibrator, and explore the effective working frequency of the piezoelectric vibrator. The modeling parameters of the piezoelectric vibrator are shown in Table 1. Figure 2(a)(b) shows the first few modes of the piezoelectric vibrator, It can be clearly seen from the figure that

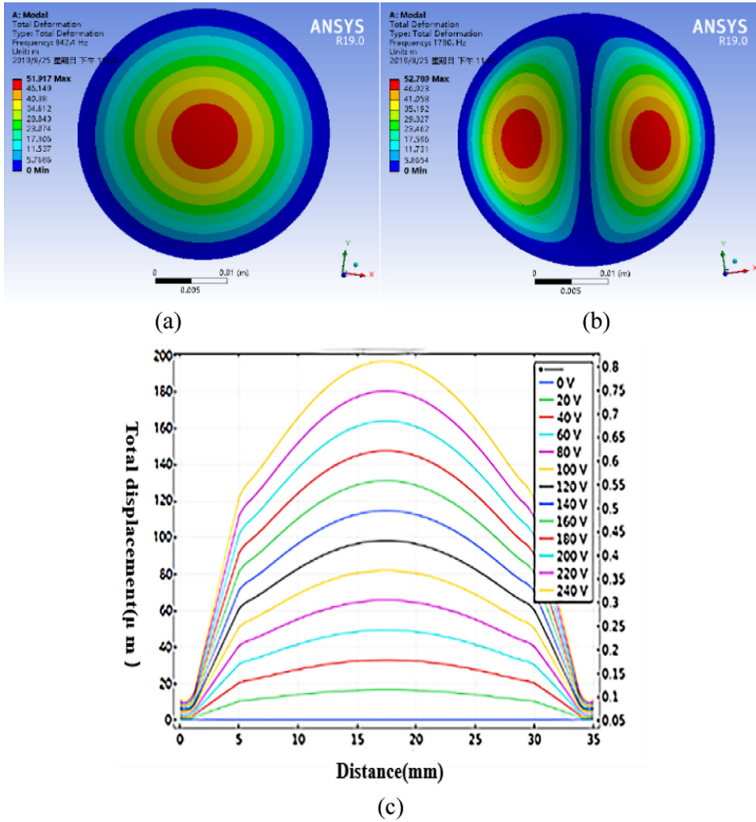


Fig. 2. Piezoelectric vibrator simulation results (a) first-order mode (b) second-order mode (c) The relationship between voltage and center displacement of piezoelectric vibrator.

Table 1. Material parameters of piezoelectric vibrator.

Material name	Diameter/mm	Thickness/mm	Density/kg.m	Elastic Modulus/GPa	Poisson's ratio
PZT	25	0.1	7600	63	0.32
Beryllium Bronze	35	0.1	8920	118	0.35

the deflection of the first-order mode shape gradually and uniformly increases from the edge of the piezoelectric vibrator to the center of the circle. The other vibration modes are irregularly and unevenly distributed. According to the working principle of the piezoelectric pump, in order to maximize the output flow, the cavity generated by the disturbance should also be the largest. Therefore, only in the first-order vibration mode, the piezoelectric vibrator can produce the largest volume change in the pump

cavity. Therefore, the frequency of the selected AC voltage is smaller than the first-order frequency of the piezoelectric vibrator, which is 842 Hz.

After studying the vibration shape of the piezoelectric vibrator, the frequency range of the input alternating current is determined. In order to further explore the relationship between different voltages and the displacement of the center of the piezoelectric vibrator, the coupling analysis of piezoelectric and solid mechanics was performed on the piezoelectric vibrator using COMSOL software. Figure 2(c) shows the vibration displacement diagram of the piezoelectric vibrator when a voltage of 0–220 V is applied. It can be seen from the figure that the overall deformation of the piezoelectric vibrator is arched and reaches the maximum value at the center of the circle, which is consistent with the vibration state of the previous model simulation. It can also be seen from the figure that as the voltage increases, the displacement of the center point of the piezoelectric vibrator gradually increases, and the center point displacement reaches 181 μm at 220 V. The above simulations directly prove the feasibility of this design.

4 Device Preparation

In this paper, because of the small size, high integration, and complex structure of the device, it is difficult to use ordinary preparation methods. Therefore, in order to prepare better devices, MEMS technology is used to make piezoelectric vibrators, and the shell is made by 3D printing. The flow chart of the piezoelectric vibrator manufacturing process is shown in Fig. 3(a). First, mirror polishing is performed on the surface of beryllium bronze and PZT, and a Cr/Ag (30 nm/400 nm) electrode is sputtered on the mirror polished side of the PZT to form a fine electrode layer. Then a layer of conductive silver paste is screen printed on the Ag electrode layer of PZT as an intermediate layer. When the beryllium bronze and the prepared PZT are bonded together in a vacuum drying oven, the bonding pressure is 0.1 MPa, and the temperature rises from 60 °C to 175 °C, with a 15 °C gradient every 10 min, and heat preservation at 175 °C more than 1 h. After bonding, the thickness of the PZT is reduced to about 100 μm by mechanical grinding and polishing is performed. Then the Cr/Ag layer as the upper electrode was sputtered onto the thin PZT layer, and finally the device was processed for lead wires [7]. As shown in Fig. 3(b), it is the actual picture of the piezoelectric vibrator after fabrication.

The aforementioned shell is made by 3D printing. 3D printing adopts a layer-by-layer stacking method, so devices with more complex structures can be printed quickly and easily. The main steps of printing the shell are as following. First, the pump model is designed in Solidworks 3D software. Then it is saved in stl format and imported into Creality 3D software. The stl file is converted into G code and imported into the 3D printer. Then the printer is started to run, the printing material PLA is melted and extruded from the printer nozzle according to the system requirements, and deposited in the designated position, after a period of time, the shell is printed and formed [8]. The printed physical map is shown in Fig. 3(c). After the shell is printed and formed, it is assembled according to the working principle described above, and the physical picture after assembly is shown in Fig. 3(d).

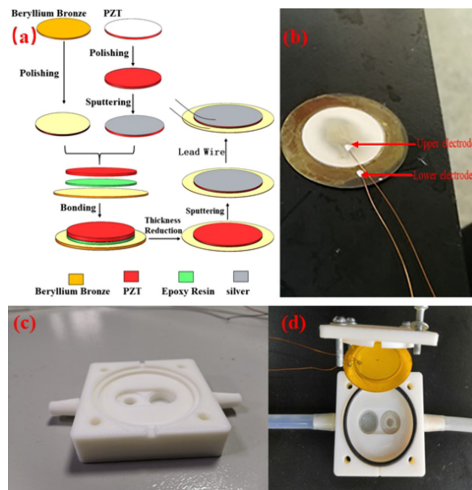


Fig. 3. Production of piezoelectric pump (a) Production flow chart (b) Physical map (c) Pump body (d) Assembly exploded view.

5 Experimental Test and Analysis

After the device is assembled, the prerequisite to ensure that the device can work normally is that the piezoelectric vibrator can have enough displacement at the external AC voltage input. Therefore, this article first built a test platform to test the vibration displacement of the piezoelectric vibrator, as shown in Fig. 4(a). Under a series of AC voltage input with a frequency of 50 Hz, the voltage displacement graph shown in Fig. 4(b) is obtained. It can be seen from the figure that the maximum displacement of the center of the piezoelectric vibrator has a linear relationship with the input voltage, which increases with the increase of the voltage, which is consistent with the previous simulation experiment. And the maximum center displacement is $136 \mu\text{m}$ under the input voltage of 220 V, which shows that the device has certain actual working ability.

In order to prove the practicability of the piezoelectric pump, this paper carried out an experiment using the piezoelectric pump to pump water to cool the PTC heating element. Figure 4(c) shows the experimental graph, and the experimental data are shown in Fig. 4(d). In general, the temperature of the PTC heating element is reduced by about $20 \text{ }^\circ\text{C}$ on average and the maximum output flow reached 159 ml/min. This proves the practicability and large flow output characteristics of the piezoelectric pump.

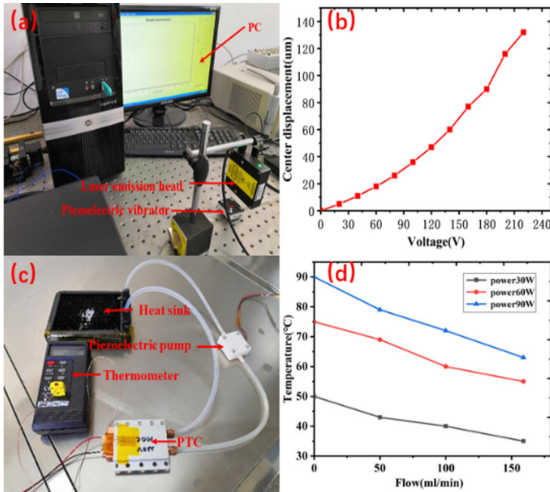


Fig. 4. Test platform and results (a) Center displacement test platform (b) Curve of between voltage and center displacement(c) Cooling PTC experiment (d) Relationship between flow output and equilibrium temperature.

6 Conclusion

This article mainly describes a piezoelectric pump based on a single piezoelectric vibrator under MEMS technology. The piezoelectric vibrator in the piezoelectric pump is made by bonding PZT and beryllium bronze substrate in a concentric circle combined with MEMS technology, the whole shell is made in one piece using 3D printing, and then assembled manually. Under the excitation of 220 V 50 Hz low-frequency AC voltage, the measured maximum displacement of the center of the piezoelectric vibrator is 136 μm . Finally, the device was tested for the practicality of cooling PTC by pumping water at a room temperature of 26 $^{\circ}\text{C}$. It was found that the device can reduce the temperature of the PTC by about 20 $^{\circ}\text{C}$ and the maximum output flow reached 159 ml/min under the same conditions.

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