



# Study on Double Piezoelectric Layers Driven Pump Based on MEMS and 3D Printing

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**Abstract.** A piezoelectric pump of small size, compact structure, light weight and large flow rate has been developed in this paper. The pump consists of two circular piezoelectric vibrators, two valve covers and three check valves. Furthermore, two circular piezoelectric vibrators made by MEMS technology are proposed as the dual transducer of the pump body. The simulation analysis consequences show that beryllium bronze is optimal metal material as substrate of piezoelectric vibrator, compared with other metal materials including alloy steel, titanium alloy and aluminum alloy. A prototype of the piezoelectric pump, with the external dimensions of 40 mm × 40 mm × -20 mm, was made by 3D printing technology that can replace conventional techniques and greatly shorten the processing cycle. The experimental results show that water risen 5 mm through the inlet pipe, when double piezoelectric vibrators were driven by AC voltages.

**Keywords:** MEMS technology · Double vibrators · 3D printing

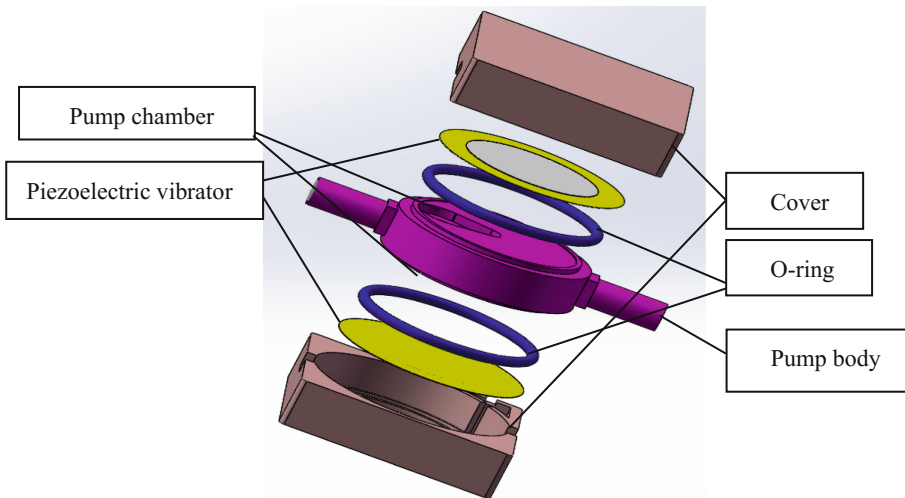
## 1 Introduction

Piezoelectric pumps have been developed in recent years and their typical operate mode is driven by piezoelectric vibrator to produce positive fluid flow. The piezoelectric pump has the advantage of small volume, compact structure, light weight and no electromagnetic interference. It is easy to be processed and produced. Therefore, It is widely used in the fields of cooling of electronic devices, fuel cells, medical research, aerospace and lubrication of mechanical equipments. Especially, piezoelectric pumps are widely used in the cooling of electronic equipment because of low energy consumption and low operating noise. With the development of diversification, complication and integration of electronic devices, heat will be gradually increased. Because air-cooling dissipation has many limitations in the application of electronic products. So the research on compact, lightweight and large-flow liquid micropumps is of great significance. For large-flow piezoelectric pumps, many scholars at home and abroad have done similar thorough research. For example, Los Angeles scholars, the University of California, used piezoelectric stacks as drivers of piezoelectric pump to achieve a flow rate of 3 L/min. But the pump was finished with the dimensions of 38 mm × 140 mm (length × width). The advantage of the piezoelectric stack drive is

that the output force is large. But the cost of the pump is high, and it is not conducive to miniaturization [1–7]. A two-chamber series piezoelectric pump, driven by double piezoelectric vibrator, is low in cost, and the overall volume of the pump is reduced to  $40\text{ mm} \times 40\text{ mm}$ . So the structure is simple. The structure of the single vibrator piezoelectric pump is easy to control the thickness of the pump body with only one piezoelectric vibrator working, which is suitable for micro-pumps with small precision driving flow requirements. Thus, its working performance has certain limitation [8, 9]. The PZT thick film in the preparation of piezoelectric vibrators usually adopts the traditional process of screen printing. The main disadvantage is that the sintering temperature is high and the prepared thick film has high porosity and low density [10]. In this paper, the piezoelectric vibrators based on MEMS technology are used as the double driver of the pump. Furthermore, the structure of the pump is fabricated based on the 3D printing technology. The experimental results demonstrate that the performance of the piezoelectric pump is better than others. Firstly, the displacement of piezoelectric vibrator reaches  $45\text{ }\mu\text{m}$ .

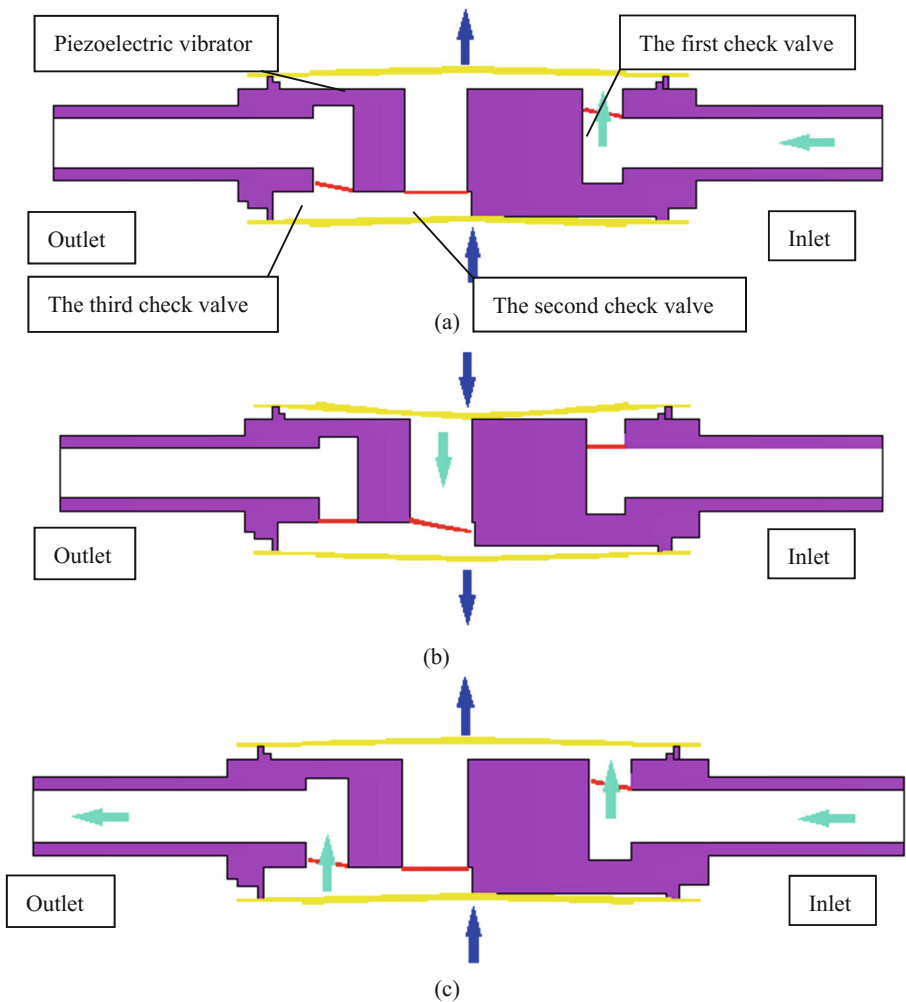
## 2 Structure and Principle

The piezoelectric pump mainly consists of two covers, two O-rings, two piezoelectric vibrators, a pump body and three check valves. As shown in Fig. 1, The two piezoelectric vibrators are fixed on pump body through the O-rings. The second check valve usually in the lower chamber separates the two chambers, which is both the outlet valve of the upper chamber and the inlet valve of the lower chamber.



**Fig. 1.** Exploded view of the piezoelectric pump

Figure 2(a), (b) and (c) show the pumping mechanism. These two processes are called suction process and discharge process, respectively. The voltage driven oscillation of the PZT device creates a cyclic displacement. Firstly, two piezoelectric vibrators move upward, the volume of the first pump chamber becomes larger by the decreasing pressure. The first check valve opens with the fluid entering the upper pump chamber. It is called the suction process I as shown in Fig. 2(a). As two piezoelectric vibrators move downward, the volume of the upper pump chamber is decreased, and the pressures in the chambers are increased. At the same time, the volume of the lower pump chamber is increased, and the pressures in the chambers are decreased. Responding to the change in pressure, the first check valve closes, and the second



**Fig. 2.** Flow state during suction process and discharge process. (a) suction process I, (b) suction process II, (c) discharge and suction process

check valve opens. Meanwhile, the liquid flows into the second chamber. It is called the suction process II as shown in Fig. 2(b). Finally, the discharge process is shown in Fig. 2(c). As the lower piezoelectric vibrator move upward, the volume of the lower pump chamber is decreased, and the pressures in the chambers are increased. The second check valve closes, and the third check valve opens. So liquid in the lower chamber moves into the outlet. The fluid is aspirated into the upper pump chamber simultaneously. Repeat the above process, liquid moves continuously from the inlet to the outlet.

### 3 Processing Technology

#### 3.1 MEMS Process of Piezoelectric Vibrator

In this experiment, beryllium bronze is used as the substrate and PZT material is used as the upper layer. The specific process flow is as follows [11]:

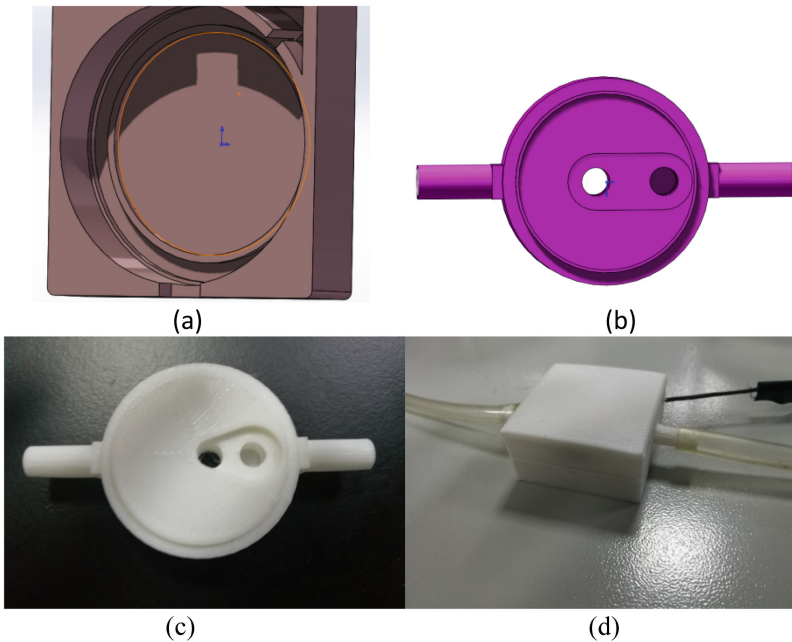
- (1) Cleaning the beryllium bronze with acetone, removing various organic and inorganic impurities on the surface of the substrate and drying;
- (2) The beryllium bronze surface layer was glued to the PZT having a thickness of about 400  $\mu\text{m}$ .
- (3) The optimum thickness of the the PZT was thinned to the 20–30  $\mu\text{m}$  after rough grinding and fine grinding.
- (4) Making upper electrode: Firstly, a 30 nm thick metal chromium was sputtered on the surface of the substrate to increase the adhesion of the metal. Then Ag (argentum) with thickness of 200 nm to increase conductivity was sputtered on the surface of the chromium, as shown in Fig. 3.



**Fig. 3.** Piezoelectric vibrator

### 3.2 3D Printing Process

The 3D printing type which is similar to the method of squeezing toothpaste has the advantages of low price, small size and relatively being prone to generating operations. The piezoelectric pump body can be processed by 3D printing rapid prototyping technology. The main operation steps are to design the pump model in solidworks 3D software as shown in Fig. 4. Then it's saved the file as stl format and imported into the Creality 3D software. After converted to G code, the printer starts to run and then melts the nozzle so that the plastic material PLA was melted and squeezed out from the nozzle, which was deposited at the specified position. The piezoelectric pump body measured 40 mm × 40 mm × 20 mm (length × width × height). The pump chamber (Ø32 × 0.4 mm) is linked to the inlet and outlet pipes (Ø6 × 10 mm). The check valves (Ø10 × 0.1) consisted of PET materials is incised by a laser cut. The O-ring (Ø36 mm × 1) is integrated to pump chamber. Finally, the upper pump is tightly glued to lower pump by AB glue. The model and material object are demonstrated in Fig. 4 (a), (b), (c) and (d), respectively.



**Fig. 4.** The model and material object (a) Cover model (b) Pump body model (c) Pump body material object by 3D printing (d) Fabricated piezoelectric pump

### 4 Simulation Analysis

The mechanical deformation of the piezoelectric vibrator made by MEMS technology changes the volume and pressure of the pu(a)mp chamber and it's crucial to the performance of the piezoelectric pump. The circular piezoelectric vibrator consisted of metal substrate and PZT.

The deformation amount of vibration of different types of substrate materials will have a large difference, which will affect the performance of the piezoelectric vibrator and directly affect the working effect of the pump. In the simulation analysis, the selected substrate has diameter of 35 mm and thickness of 0.4 mm; the piezoelectric ceramic has diameter of 25 mm and thickness of 0.2 mm; the applied AC voltage is 100 V; the final static deformation of the piezoelectric vibrator is shown in Fig. 5. The center displacement of the vibrator is shown in Table 1. Choosing the appropriate metal substrate is the basis for the design and testing of the piezoelectric pump.

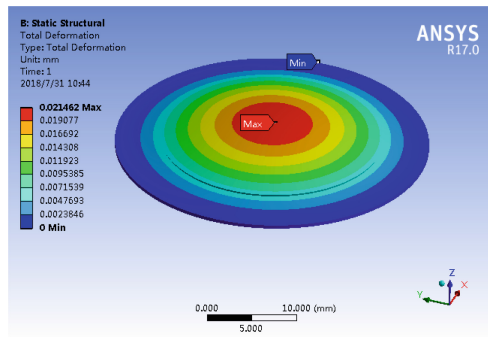


Fig. 5. Static deformation

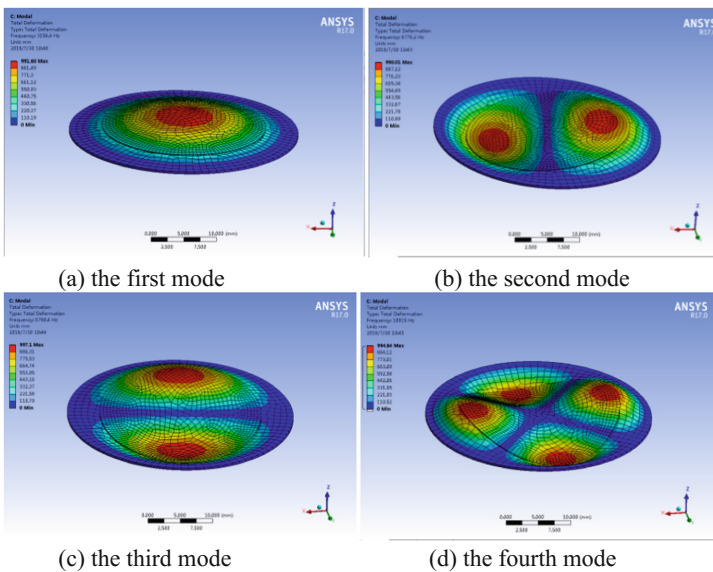
Table 1. Piezoelectric transducer center point displacement

Substrate material	Piezoelectric vibrator center deformation (μm)
Alloy steel	21.5 μm
Bronze bronze	29.3 μm
Titanium alloy	31.9 μm
Aluminum alloy	38.8 μm

From Table 1, it can be determined that: different metal materials are used as the substrate, and the center displacement of the piezoelectric vibrator is different. The aluminum alloy as the substrate produces the largest displacement, followed by the titanium alloy, the beryllium bronze and the alloy steel center. In addition to considering the influence of the size of the center displacement, it is also necessary to comprehensively consider the conductivity, processing technology, weldability and blocking properties of the substrate. Since the aluminum alloy having a small hardness,

which is susceptible to deformation in vibration and affects the effect of the piezoelectric vibrator. Furthermore, the titanium alloy is not suitable for use because of its high electrical resistivity. In conclusion, beryllium bronze is finally used as the substrate material.

The analysis of the dynamic characteristics of a circular piezoelectric vibrator mainly including the analysis of the natural frequency and mode shape, which are only related to the structure of the piezoelectric vibrator itself. For a passive valve piezoelectric pump, if the frequency of the piezoelectric vibrator is close to the natural frequency, the system will resonate and the output maximal. The four modes of the vibration mode simulated by the previously selected piezoelectric vibrator are shown in Fig. 6 and the corresponding natural frequencies are shown in Table 2. It can be seen from the vibration pattern that the first mode of the circular piezoelectric vibrator is arched. This mode is similar to the vibrator in static analysis; the second mode is a convex-concave symmetric surface; the third mode is concave at both ends. Symmetrical surface; the fourth mode is a convex surface with two convexities and two concaves.



**Fig. 6.** The four modes of the piezoelectric vibrator

**Table 2.** Natural frequency of the first four orders of piezoelectric vibrators

Order	The first level	The second order	The third order	The fourth order
Natural frequency (HZ)	3156	6776	6780	10915

It can be seen from the vibration pattern that only the deflection of the first mode is gradually increasing from the edge of the vibrator to the middle position and has good symmetry. In this vibration mode, the combination of the vibrator and the pump body can produce the largest pump chamber volume. Therefore, the operating frequency of the piezoelectric pump power supply should be close to the first-order natural frequency of the piezoelectric vibrator.

## 5 Experiment and Result Analysis

### 5.1 Experimental Test

To test the output performance of the piezoelectric pump, an experimental system was set up and it is shown in Fig. 7. The experimental temperature is of 25 °C and water was utilized as the working medium.

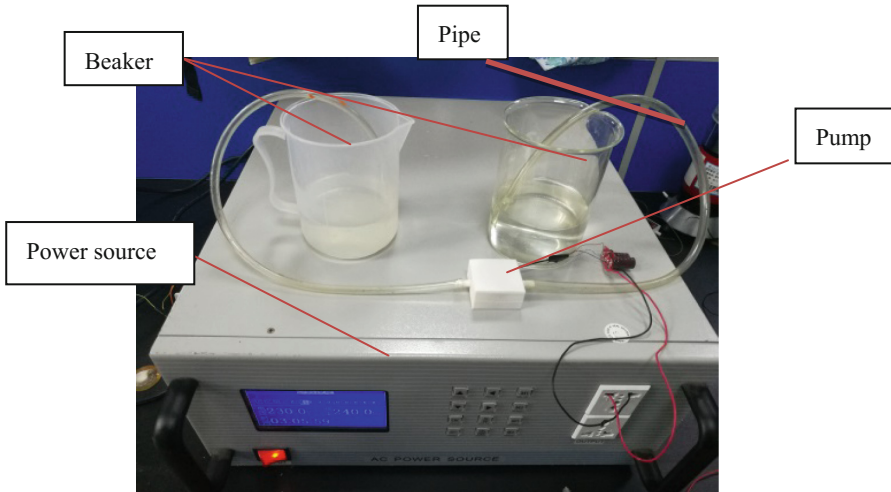


Fig. 7. Experimental devices of performance test

### 5.2 Results and Discussion

When the driving voltage is 200 V at a frequency of 150 Hz, water only rises 5 mm through the inlet pipe. But the result isn't optimal, the main reasons are as follows:

- (1) Poor sealing performance between piezoelectric vibrator and O-ring.
- (2) Displacement of the piezoelectric vibrator driven by AC voltages is not enough.

According to the above reasons, We will strengthen sealing performance between piezoelectric vibrator and O-ring and optimize design of piezoelectric vibrator in later stages.



## 6 Conclusions

A driven piezoelectric pump with prominent working features is presented in this paper, which is fabricated by the MEMS techniques. The piezoelectric pump body is fabricated by 3D printing technology. Compared with others, The piezoelectric pump with dimension of 40 mm × 40 mm × 20 mm have advantage of small volume, compact structure, light weight. The simulation analysis consequences show that beryllium bronze is optimal metal material as substrate of piezoelectric vibrator. Based on test results and reasons, we will optimize performance of piezoelectric pump in the near future.

**Acknowledgments.** This work was supported by Jiangxi Science and Technology Support Project (20151BBE50044).

## References

1. Valdovinos, J., Williams, R.J., Levi, D.S., et al.: Evaluating piezoelectric hydraulic pumps as drivers for pulsatile pediatric ventricular assist devices. *J. Intell. Mater. Syst. Struct.* **25**(10), 1276–1285 (2014)
2. Zhang, Z., Wang, W., Chen, X.: Study on the performance of piezoelectric micro pump for insulin injection. *Chin. J. Med. Instrum.* **39**(1), 64–67 (2015)
3. Research on water cooling system of computer chip whose power source is pressure electric pump. Jilin university (2005)
4. Ludwigs, A.: Micropumps-past, progress and future prospects. *Sens. Actuators* **105**(1), 28–38 (2005)
5. Liu, J., Sun, X., Liu, G., et al.: Experiment on dual-chamber parallel piezoelectric stack pump for electrorheological fluids. In: International Conference on Mechatronics and Automation. IEEE (2011)
6. Doll, A., Heinrichs, M., Goldschmidtboeing, F., et al.: A high performance bidirectional micropump for a novel artificial sphincter system. *Sens. Actuators, A* **130**(2), 445–453 (2006)
7. Peng, T.: Investigation on piezo-pump used in water-cooling-system for computer CPU Chip. *J. Refrig.* **30**(3), 30–34 (2009)
8. Shou, L., Yao, L.Q., Wang, Y.H., et al.: A kind of concentric piezoelectric membrane micropump for medical use. *Piezoelectrics Acoustooptics* **6**, 021 (2005)
9. Kim, J.H., Kang, C.J., Kim, Y.S.: A disposable polydimethylsiloxane-based diffuser micropump actuated by piezoelectric-disc. *Microelectron. Eng.* **71**(2), 119–124 (2004)
10. Ullmann, A.: The piezoelectric valve-less pump - performance enhancement analysis. *Sens. Actuators, A* **69**(1), 97–105 (1998)
11. Nong, N.V., Samson, A.J., Pryds, N., et al.: Microstructure and thermoelectric properties of screen-printed thick films of misfit-layered cobalt oxides with Ag addition. *J. Electron. Mater.* **41**(6), 1280–1285 (2012)
12. Tang, G., Yang, B., Hou, C., Liu, J., et al.: A piezoelectric micro generator worked at low frequency and high acceleration based on PZT and phosphor bronze bonding. *Sci. Rep.* **6**, 38798 (2016)