A PZT Liquid Pump Made of the Piezoelectric Ceramic with Low Power and High Flow Rate

Shiuan-Ho Chang, Chaoying Liu, Xiahui Wang, Ying Jun Chen, Z. Y. Xu, Shih-Sheng Liu, and Min Zhou

Abstract—**Piezoelectric pumps possess many advantages such as quiet operation, quick response, simple structure, and nonelectromagnetic radiation. This paper presents a PZT (Lead zirconate titanate) liquid pump with low power, high flow rate, small size, and light weight. The liquid pump is composed of the piezoelectric ceramic, elastomer valve, and PET (Polyethylene terephthalate) pump body. The power consumption, flow rate, body size and weight of the pump are 1 W, 800 ±5% ml min^{-1}, 50 ×50 ×10 mm., and 50 g, respectively. Additionly, the pump works at an exciting voltage of 50 Hz, 40 V. According to the applied voltage or frequency to a PZT pump, the flow rate of the fluid is able to be controled. Besides, the liquid pump is suitable for various fluids such as water, alcohol, soda, hydrochloric acid, etc.**

Index Terms—**Piezoelectric, pump, ceramic, liquid, PZT.**

I. Introduction

PZT piezoelectric ceramics are widely used for numerous electronic devices such as resonators, sensors, actuators, high-power transducers, and capacitors [1–5]. For examples, a proposed linear piezoelectric actuator can produce elliptical movements on the horns' tip ends [6]. Lin [7] exhibited a cymbal transducer composed of metal caps in flexural vibration, a piezoelectric ceramic ring and a metal ring in radial vibration. Tong *et al.* [8] presented that Zn addition in 0.7Bi1-xZnxFeO3-0.3BaTiO3 ceramics effectively improved the microstructure, electrical properties, temperature stability and sensitivity of sensors for high temperature piezoelectric applications. Recently, a PZT pump is widely developed and applied in life as it has the advantages of high energy efficiency, moderated displacement, good reliability, and fast response time [9]-[12]. On the basis of the converse piezoelectric effect of a PZT, transformation from electrical energy to mechanical energy for a pump is feasible. The PZT pump is stabler than other pumps, and the flow rate of the liquid is related to the magnitude and frequency of the applied voltage [13]-[15]. In recent years, a variety of piezoelectric motors or pumps were presented [16]-[19]. Cazorla *et al*. [20] developed a functional micro-pump made of silicon and PZT thin films, and obtained the water flow rate of 3.5 μL/min at 1 Hz, 24 V actuation voltage. Wang *et al*. [21] presents a piezoelectric micropump with high flow rate, high pumping pressure, and lower power consumption, which is favorable for the fuel delivery system. Moreover, Wang *et al*. [22] presented a motor whose stator is a sandwich structure of two PZT rings and an elastic metal body. The maximum non-loaded rotating speed and maximum output torque of the prototype respectively are 117 rpm and 0.65 Nm at an exciting voltage of 40 Hz, 134 V. Differring from the above, this work developed a PZT liquid pump with low power, high flow rate, small size, light weight, no electromagnetic interference and mechanical wear, and no maintenance. The liquid pump works at an exciting voltage of 50 Hz, 40 V and is composed of the PZT, Cu sheets, elastomer valve, and PET (Polyethylene terephthalate) pump body as shown in Fig. 1 (a) - (e). Furthermore, the power, flow rate, body size and weight of the pump are 1 W, 800 ±5% ml min-1, 50 ×50 × 10 mm., 50 g, respectively. Some practicality pictures are used to elaborate the mechanism of the PZT pump.

II. Experimental

A PZT of 0.3 mm thick film, which is fabricated by the tape casting process and coated a silver layer on both upper and lower surfaces, is pasted onto a copper sheet to form a PZT oscillator, as illustrated in Fig. 1 (a). The Sn is welded on the upper and lower surfaces of a PZT oscillator to form the electrodes through which the exciting voltage of 50 Hz, 40 V is applied to the PZT. Besides, Fig. 1 (b) shows the bottom part of the pump body made of the PET with an inlet valve of the elastomer, O-ring, and an outlet hole. Relatively, the top PET part only contains an O-ring, as revealed in Fig. 1 (d). The PZT oscillator is put into the bottom part and then covered by the top part to mold a PZT pump, as illustrated in Fig. 1 (c) - (e). Meanwhile, a liquid chamber is formed between the PZT oscillator and the bottom part of the pump. The pressure and volume of the liquid chamber change with the stretching or compressing force built from the PZT.

On the other hand, the exciting voltage circuit shown in Fig. 2 is designed by use of the MC34063 and NE555 integrated circuits, in order to respectively fabricate a DC-DC boost circuit as well as a full-bridge voltage inverter circuit [23-25].The input is a 9V DC voltage supplied from a lithium battery and the DC-DC boost converter (MC34063) transfers from 9V to 40V, a higher DC voltage. Moreover, the 9V DC voltage is adjusted to 5V DC to apply to the NE555 IC by a LM7805 regulator. Subsequently, a

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full-bridge inverter circuit transfers from 40V DC voltage to a square wave of 40V, 50Hz AC voltage through the NE555 integrated circuit.

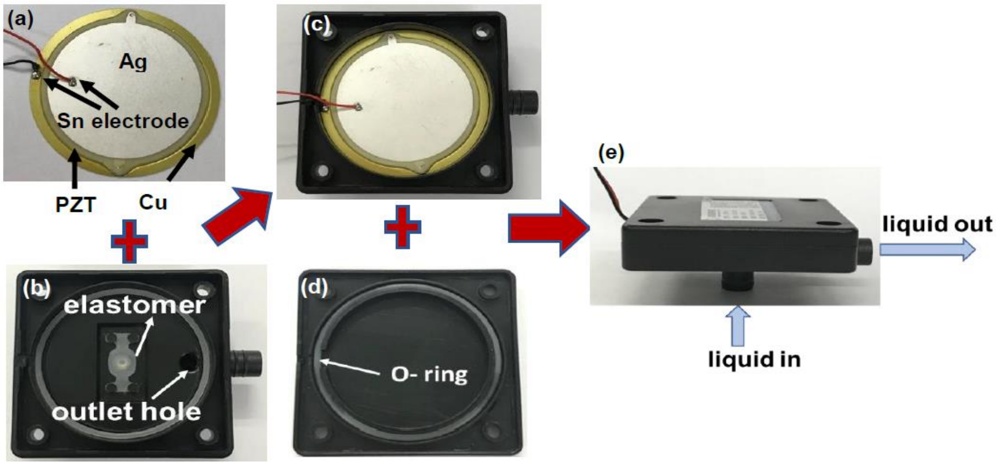

Fig. 1. Pictures of the parts of a PZT pump : (a) A PZT oscillator (b) Bottom part (c) A PZT oscillator in the bottom part (d) Top part (e) A forming PZT pump.

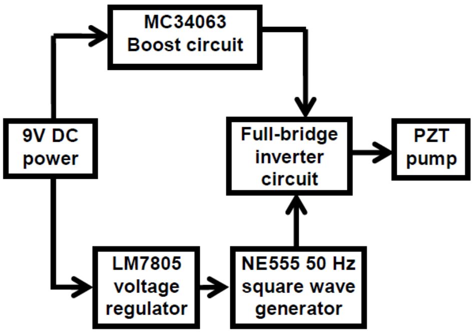

Fig. 2. A flowchart of generating a 40V, 50Hz AC voltage for a PZT liquid pump.

III. Results and Discussion

A. Converse Piezoelectric Effect of a PZT

A PZT exhibits the direct piezoelectric effect (the generation of electricity when the stress is applied) and also exhibits the converse piezoelectric effect (the generation of the stress when an electric field is applied). In this work, the converse piezoelectric effect of a PZT is a crucial mechanism for the liquid pump. As shown in Fig. 3 (b) - (c), when a specified electric field is applied to a PZT, the stretching force occurs while the compressing force happens at a reverse bias voltage. Thereby, when an exciting voltage of 50 Hz, 40 V is applied to the PZT, the stretching and compressing forces occur periodically. Because the PZT is pasted onto a copper sheet that is harder than the PZT and although the bending of the PZT body is not obvous, the stretching force can pull the PZT oscillator up but the compressing force can push it down.

B. Operating Principle of A PZT Liquid Pump.

The operating principle of the proposed PZT liquid pump is presented in Fig. 3. As presented in Fig. 4(b) - 4(c) , when the PZT oscillator is pulled up to increase the liquid chamber volume accompanying a decreased chamber pressure, the liquid around the inward bending elastomer can be sucked into the chamber easily and rapidly. Relatively, when the PZT oscillator is pushed down to decrease the liquid chamber volume accompanying an increased chamber pressure, the inlet elastomer valve closes and the liquid flows out through the outlet hole. Thus, the outside liquid is able to be pulled into the liquid chamber through the intlet automatically, and the liquid ceaselessly flows out through the outlet hole as illustrated in Fig. 4(c). In addition, according to the applied voltage or frequency to a PZT pump, the flow rate of the fluid is able to be controled freely. The relationship between the flow rate and the applied voltage or frequency to a PZT pump will be studied in the future. Fig. 5 shows the running PZT liquid pump in an aquarium. As illustrated in Fig. 5, the water flow is large, smooth and steady whereas the pump is very quiet as well as low noise. Fig. 5 states that the designed PZT liquid pump is applied in life successfully.

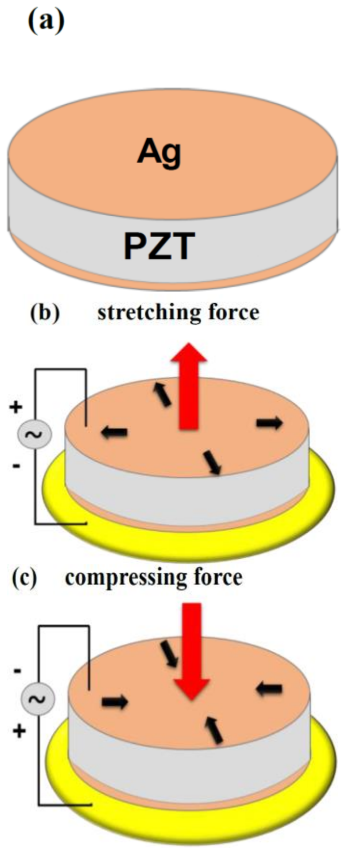

Fig. 3. Schematic diagram for the converse piezoelectric effect of a PZT oscillator: (a) No electric field (b) Stretching force (c) Compressing force.

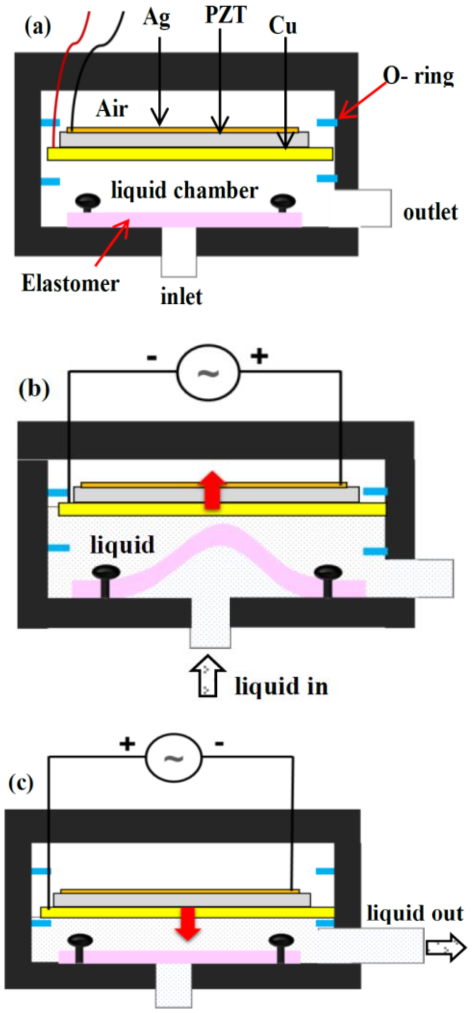

Fig. 4. Schematic diagram for the operating principle of a PZT liquid pump : (a) No electric field (b) PZT oscillator pulled up (c) PZT oscillator pushed down.

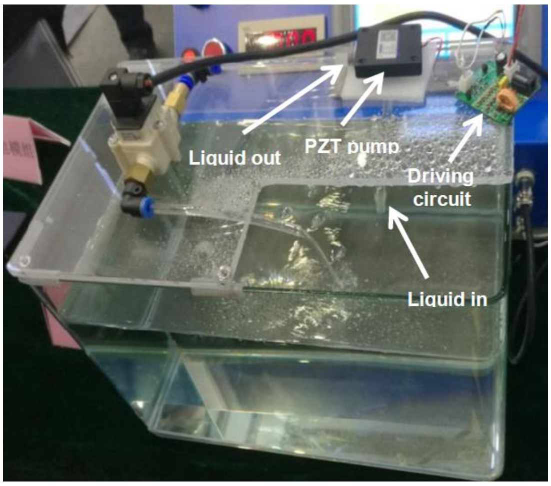

Fig. 5. A picture of a running PZT liquid pump applied to an aquarium.

IV. Conclusions

In the present contribution, a PZT liquid pump has been developed successfully. The liquid pump is suitable for various fluids such as water, alcohol, soda, hydrochloric acid, etc. Besides, the PZT pump poessesses many advantages such as small size, light weight (50 g), low power consumption (1W), easily being controlled, no electromagnetic interference and mechanical wear, and no maintenance. Furthermore, the PZT pump has a high flow rate of 800 ±5% ml min-1 at the exciting voltage of 50 Hz, 40 V. The simple design PZT pump can widely be applied in life such as aquariums, landscaping, etc.

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