Simulation of raindrop-shaped flow tube valveless piezoelectric pump

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Abstract. In order to promote the application of raindrop-shaped flow tube valveless piezoelectric pump (RSFTV PZT pump), basing on the existing research, the RSFTV PZT pump was simulated by computer. Firstly, the existence of the flow resistance of the flow tube was proved by simulation of FLUENT. Then, the dynamic mesh analysis of the pump was carried out to simulate the pumping flow rate at different driving frequencies. Lastly, the simulated results were compared with the experimental results, which shows that the flow rate tendency and value obtained by simulation are basically consistent with that by experiment. The simulation of the RSFTV PZT pump would be helpful to further accelerate related researches and promote the application of RSFTV PZT pump in MEMS and other fields.

1. Introduction

The valveless piezoelectric pump (PZT pump) is a low-cost piezoelectric actuator and is widely used as an actuator in microfluidic field, taking advantage of the inverse piezoelectric effect which makes the piezoelectric vibrator deformed, capable of pumping fluid in one priory direction when combined flow resistant mechanism [1-3]. Valveless PZT pump, when compared with the traditional motor pump, has many advantages such as compact size, no electromagnetic interference, and easy miniaturization, has shown ever-increasing potential in the field of MEMS [4-6].

Stemme et al. proposed a valveless PZT pump which contains a piezoelectric vibrator, a nozzle, a diffuser, and a pump chamber, in 1993 [7,8]. It’s the very first time for the nozzle/diffuser (there are many scholars name it as conical flow tube or cone-shaped tube) dancing on the arena of valveless PZT pump. This first try by Stemme, arouses worldwide scholars’ interest to further investigate the nozzle/diffuser in volume-type valveless PZT pump, has extremely promoted the development of valveless PZT pump in the field of micro pumping [9,10]. Gerlach et al. further simulated and studied the dynamic flow and dynamic mechanism of nozzle in 1995 [11]. Kolahdouz et al. studied the effects of driving voltage waveforms and frequencies on the performance of conical flow tubes, and simulated the internal flow field changes using computer simulation software in 2014 [12]; He et al. optimized the structure of the traditional valveless PZT pump with cone-shaped tube by the computational simulation with different initial and boundary conditions, to determine the best parameters for the cone-shaped tube in 2016 [13-15].

Based on a raindrop-shaped flow tube valveless PZT pump (RSFTV PZT pump) proposed in [16], this internal flow field and flow resistance were analyzed by computer simulation. In this paper, three-dimensional modeling software was used to construct RSFTV PZT pump whose internal flow field was simplified. Secondly, the flow field was meshed by the meshing software. Finally, the simulated flow...
rate results of the RSFTV PZT pump by software FLUENT, under dynamic grid of pump chamber and different pressures setup in inlet and outlet, were compared with the experimental results in [16]. This study will provide a theoretical basis for the further application of the RSFTV PZT pump.

2. Structure and working principle

2.1. Structural Parameters
The sectional views of the raindrop flow tube and RSFTV PZT pump are shown in Figures 1 and 2, respectively. The RSFTV PZT pump is mainly composed of a pump body, a pump chamber, two flow tubes and a piezoelectric vibrator. For the flow tube, we determine forward flow direction as the direction from big side to small side of “raindrop” in the flow tube. Vice versa, the backward flow direction is determined. The basic size parameters of the RSFTV PZT pump are shown in Table 1.

2.2. Working Principle
When the vibrator bulge downward under the excitation of the driving voltage, the pump chamber volume increases and the internal pressure becomes smaller, the fluid enters the pump chamber through the two flow tubes (suction stroke). When the vibrator bulge upward, the pump chamber volume decreases and the pressure increases, the fluid is discharged from the pump chamber through the flow tubes (compression stroke). The pumping effect is achieved macroscopically, due to the reciprocal place of the flow tubes which can be achieved different flow resistance when fluid flow in forward and backward direction of it.

3. Simulation

3.1. Flow Resistance Analysis
The flow resistance of the flow tube was calculated by computational simulation. The fluid medium used for the simulation was water with a density of 1 g/cm³, a kinematic viscosity coefficient of 1.01, and a temperature of 20°C. The fluid area for simulation was constructed at first, then the steady state calculation of FLUENT—the pressure difference between two orifices of a flow tube is 600 Pa, 800 Pa, 1000 Pa, 1200 Pa and 1400 Pa—was used to simulate the forward flow rate and the backward flow rate within one minute.
The simulating results are shown in Figure 3. As the pressure difference between the two orifices of the flow tube increases, the flow rate increases no matter whether in the forward or backward flow. What’s more, under any pressure difference, the forward flow rate is always larger than the backward flow rate. These phenomena indicate that there is a significant difference of flow resistance in the flow tube when fluid flowing through it in two direction.

![Fig.3 Relationship between pressure difference and flow rate](image)

### 3.2. Flow Rate Analysis

In order to obtain the internal flow field of the RSFTV PZT pump, the flow field of the pump was constructed and simplified. The dynamic mesh model of the vibrator was established to analyze the pumping characteristics of the RSFTV PZT pump at different frequencies. The transient calculation was applied to the simulation. The amplitude of the vibrator under different voltage is different and determined by database that built up previously. All the simulation was carried out under 100 Vrms.

![Fig.4 Pressure cloud diagram of suction stroke (left) and compression stroke (right)](image)

![Fig.5 Velocity cloud diagram of suction stroke (left) and compression stroke (right)](image)

Pressure cloud diagram and velocity cloud diagram, during suction stroke and compression stroke, are shown in Figures 4 and 5, respectively. In suction stroke, the pressure in the pump chamber is less
than the pressure inside the two flow tubes, the fluid enters the pump chamber from the inlet and outlet, however, the pressure inside the left flow tube is less than that of the right. In compression stroke, the internal pressure of the pump chamber is greater than the internal pressure of the flow tubes, and the fluid in the pump chamber is under the action of the pressure through the two flow tubes, however, the internal pressure of the left flow tube is larger than that of the right. At the same time, according to the velocity cloud diagram, the flow rate of the left flow tube is significantly larger than that of the right flow tube in suction stroke, however, the flow rate of the right flow tube is significantly larger than that of the left in compression stroke.

![Fig. 6 Comparison of simulated flow and experimental flow](image)

The pumping flow rate results (simulating flow rate) obtained by dynamic mesh simulation are compared with the results (experimental flow rate) in literature [16], as shown in Figure 6. It can be seen that both the simulated flow rate tendency and the experimental flow rate tendency are consistent very well, the flow rate increases by increasing the frequency from 5-30 Hz, however, the flow rate decreases by increasing the frequency above 30 Hz. The corresponding value in a frequency point by simulation is somewhat larger than that by experiment. The rubber pipes was used to connect the RSFTV PZT pump in real experiment, however, was ignored in simulation. The rubber pipes lead to the loss of pressure which further reduced the flow rate, and account for the reason why the corresponding flow rate are always larger than the experiment’s.

4. Conclusion

In this paper, based on the existing research, the fluid field of the RSFTV PZT pump was constructed and simplified, firstly. Then the flow resistance of the flow tube under different pressure was simulated, which shows that there are obvious flow resistance in forward and backward flowing direction. The fluid analysis model of the RSFTV PZT pump was built and simulated under different frequencies by software FLUENT. The results show that the flow rate tendency and value by simulation are basically consistent with that by experiment. The simulation of the RSFTV PZT pump provides an effective theoretical basis for its further application.

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