The performance of a piezoelectric micro-pump for 3D additive manufacturing

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Abstract. The piezoelectric micro-pump is one kind of electronic device which can achieve supplying fluid on demand, and the total volume of fluid per time is at μL level. For fluid, such as fluid base on Cyanoacrylate, with low dynamic viscosity and can be solidified easily, the micro-pump is effectively to be used for 3D additive manufacturing. In this paper, we show a valve less piezoelectric micro-pump with the advantages of simple structure and stable performance. And we analyze the performance of the piezoelectric micro-pump which can be used for 3D additive manufacturing. A fluid solid coupling method is proposed for simulating the working progress of the piezoelectric micro-pump. The fluid transmission performance of the piezoelectric is mainly analyzed, such as the mass flow, flow rate of the outlet and the internal pressure distribution. The working principle of the piezoelectric micro-pump is discussed as well.

1. Introduction

The piezoelectric micro-pump is mainly used for trace fluid transmission, and is wildly used in varies kind of industrial field thank to its advantages of simple structure, easily control and good stability [1-4]. By the structure of the piezoelectric micro-pump, it can be divided into two categories, one is valve piezoelectric micro-pump and the other one is valve less piezoelectric micro-pump [5-13]. For 3D additive manufacturing, we need to control the supply solidable fluid material, in traditional, we push the fluid with a high pressure pump and control the accuracy by the control of the opening and closing of the nozzle. Fortunately, the piezoelectric micro-pump is a kind of micro electronic device which can achieve suppling a bit of fluid to the target surface. Though, there exist shortages when a high viscosity fluid is selected, for ejecting the solidable fluid which is based on Cyanoacrylate, the piezoelectric micro-pump show its advantages. The fluid material based on Cyanoacrylate is a kind of material using for the medical and biological sciences, thanks to its fast solidifying and biodegradation [14-16].

Thus, in this paper we proposed using the piezoelectric micro-pump for 3D additive manufacturing, and we analyze the performance of the micro-pump to verify the feasibility. For easy assembly and long working life, we select the valve less piezoelectric micro-pump as the device for 3D additive manufacturing, as the valve of the micro-pump is often damaged. In this paper, we taking a fluid solid coupling method to simulate the piezoelectric micro-pump. The deformations of the piezoelectric vibrator with the coupling effect at different time are given, the mass flow and fluid velocity of the
outlet of the piezoelectric micro-pump are shown as well. The pressure distribution statuses at different time when the piezoelectric is working are given. The analysis results show the piezoelectric micro-pump can be used as the device for 3D additive manufacturing.

2. Structure And Working Principle
The piezoelectric micro-pump is composed of the piezoelectric vibrator and its chamber. The piezoelectric vibrator is made by gluing the piezoelectric ceramic on a metal substrate. When pulse voltage is applied on the piezoelectric vibrator, the vibrator deforms and creates volume change of the chamber. As shown in Fig.1, due to the deformation of the piezoelectric vibrator, the chamber of the micro-pump produces two forms as shown in Fig.1 (a) and Fig.1 (b). In Fig.1, the $\Phi_1$ is the mass flow of the inlet and $\Phi_2$ is the mass flow of the outlet. Under the excitations, the piezoelectric vibrator vibrates, and the volume of the chamber reciprocating changes. When the chamber volume increases, the mass flow of the inlet is larger than that of outlet, and when the chamber volume decreases, the mass flow of the inlet is less than that of outlet. Thus, due to the mass flow difference, the fluid keeps moving from the inlet to the outlet.

![Figure 1. The working principle of the piezoelectric micro-pump [17].](image)

The structure of the piezoelectric micro-pump used in this paper is shown in Fig.2. The piezoelectric ceramic used here is PZT-5H, the material of the ceramic is PZT-5H, and the physical properties (elastic stiffness constant matrix $[c^E]$), piezoelectric stress constant matrix $[e]$ and dielectric constant matrix $[\varepsilon^T]$) of the PZT in the simulation are set as:

$$
[c^E] = \begin{bmatrix}
13.2 & 7.3 & 7.1 & 0 & 0 & 0 \\
7.3 & 13.2 & 7.1 & 0 & 0 & 0 \\
7.1 & 7.1 & 11.5 & 0 & 0 & 0 \\
0 & 0 & 0 & 2.6 & 0 & 0 \\
0 & 0 & 0 & 0 & 2.6 & 0 \\
0 & 0 & 0 & 0 & 0 & 3
\end{bmatrix} \times 10^{10} \text{(N/m}^2\text{)}
$$

$$
[e] = \begin{bmatrix}
0 & 0 & -2.4 \\
0 & 0 & -2.4 \\
0 & 0 & 17.3 \\
0 & 0 & 0 \\
0 & 12.95 & 0 \\
12.95 & 0 & 0
\end{bmatrix} \text{ (C/m}^2\text{)}
$$

$$
[\varepsilon^T] = \begin{bmatrix}
804.6 & 0 & 0 \\
0 & 804.6 & 0 \\
0 & 0 & 659.7
\end{bmatrix} \times 10^{-11} \text{(F/m)}
$$
As the piezoelectric micro-pump is used for ejecting the solidable fluid which is based on Cyanoacrylate, the fluid properties in the simulations are set depend on its real parameters. The piezoelectric vibrator used in this paper is made by gluing the piezoelectric ceramic on a copper substrate. The outer of the copper substrate is set as fixed condition, the outer the fluid domain is set as wall boundary condition, the Fluid inlet is set as pressure inlet, and the Fluid outlet is set as pressure outlet. The upper and bottom of the piezoelectric ceramic are applied on voltage boundaries as 0 V and 5 V respectively, the applied pulse voltages are shown in Fig.3.

3. Results And Discussions

3.1. Coupling results of the piezoelectric vibrator
In the simulations, we carry two way coupling analysis, when the piezoelectric vibrator is applied on pulse voltage, it deforms and create pressure on the fluid solid interface. The fluid is pushed by the piezoelectric vibrator, and the vibrator obtains the counterforce of the fluid as well. The deformation of the piezoelectric vibrator is shown in Fig.4. As we can see that, due to the fixed boundary of the outer ring of the copper substrate, the maximum deformation is created at the center part of the vibrator. The deformation of the piezoelectric vibrator causes the volume change of the chamber.

The deformation values of the piezoelectric vibrator varies with time is shown in Fig.5. Combined with Fig.3, we can see that, the deformation is created along with the applying of the pulse voltages. And when the voltage value reaches peak value, the deformation of the vibrator obtains the maximum deformation. Although the voltage is kept constant for a period of time, the deformation of the
piezoelectric vibrator does not remain stable. The reason is that, due to the action of the inertia force, the piezo vibrator continues to deform when the voltage is constant.

Figure 5. The deformation values of the piezoelectric vibrator varies with time

3.2. Coupling results of the fluid
In order to better understand the working principle of the piezoelectric micro-pump, we obtain the pressure distribution statuses at different time inside the chamber of the micro-pump with two-way fluid solid coupling effect, as shown in Fig.6. We can see that, the coupling pressure, which is created by the coupling effect between piezoelectric vibrator and fluid, first occurs on the fluid solid coupling interface. Then, the pressure spreads in the fluid domain, and then spreads to the inlet and outlet of the piezoelectric micro-pump. Because the structure of the outlet part and inlet part is different, the pressure distribution inside the chamber is asymmetric, which causes the directional flow of the fluid.

Figure 6. The pressure distribution statuses at different time
What we care about is the mass flow at the outlet of the piezoelectric micro-pump, as the mass flow reflect the fluid transform performance of the micro-pump. The coupling results of the mass flow of the outlet is shown in Fig.7. As we can see that, under three pulse voltages the mass flow of the outlet only create two peaks. It demonstrate the delay of the pressure propagation, as the fluid be regard as an elastomer. When pulse voltages are applied on the vibrator, the vibrator vibrates, and pressure creates in the fluid, then the pressure propagation in the chamber of the micro-pump, when it propagate to the outlet of the micro-pump, changes are created in the outlet. That also shows why the outlet mass flow has not changed at the beginning. Besides, we can see that the mass flow at outlet creates positive and negative values, which is consistent with the previous. At the same time, it can be seen that the total mass flow of fluid which out of the outlet is large than the fluid which is back flow into the outlet. Thus, the piezoelectric micro-pump can realize the quantitative output of fluid.

![Figure 7](image1.png)  ![Figure 8](image2.png)

**Figure 7.** The mass flow of the outlet at different time  **Figure 8.** The fluid velocity of the outlet at different time

The velocity of the fluid reflect the intensity of the piezoelectric micro-pump, thus, we obtains the fluid velocity at the $u$ direction at the outlet, as shown in Fig.8. We can see that the velocity curve of the fluid only has two peaks as well, which is due to the delay of the pressure propagation. Besides, the velocity also has positive and negative values, which reflect the outflow and inflow of the fluid at the outlet. As we can see that, the time for the velocity to be positive is large for the whole time, in other words, the general trend of fluid flow is the fluid outflow of the outlet. Thus, the piezoelectric micro-pump can achieve the quantitative control of fluid and can be used for 3D additive manufacturing.

4. Conclusions
Through the performance analysis of the piezoelectric micro-pump for ejecting the solidable fluid which is based on Cyanoacrylate, it is proved that the electronic device can be used for 3D additive manufacturing. Although back flow exist at the outlet part of the piezoelectric micro-pump, the general trend is that the fluid flows out of the outlet, and we can achieve high accuracy 3D printing by controlling the excitation signal. In the next step, we will establish experimental platform to carry out experimental research.

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