A New Approach for Analysis of Ink Jet Devices System

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Abstract

Conventionally, piezo-electric inkjet devices have been computationally simulated in two separate areas: a structure analysis of a piezoelectric actuator and a body forming flow channels and a fluid flow analysis. Individually, their results showed fair accuracy. However, the challenge of the simulations lies on making the connection between the analyses.

A new approach of combining the two different analyses is described in this paper. First, we used the conventional lumped model for an ink-jet device system except the meniscus movement in the orifice. The lumped model was divided into several components, described with simple mechanical elements. The applied electrical voltage was replaced with equivalent normal stresses on the actuator, and so the structural analysis includes the deflection of an actuator in the modeled mechanical system. Second, three-dimensional fluid analysis was implemented for the flow around the meniscus, predicting the characteristics of droplet dynamics. In order to combine their results, two analyses were set to share variables at the boundaries - the inlet velocity of the orifice and the pressure of fluid under the meniscus. The simulation results successfully predicted the dynamic response of the system and drop ejection phenomena, such as the velocity and size of droplet. To predict the optimal structure and driving signal, the results of the simulation were compared with those of the experiment in the parameter study

Introduction

The performance of ink-jet head depends not only on the inner structure of the head, but also on the input of the driving signal. The two parameters should be simultaneously considered to optimize the velocity and size of the droplet. Kyser suggested the lumped model of ink jet head with equivalent mass, spring constant and viscous damping coefficient. Beasley introduced the concept of equivalent damping length and equivalent inertia length to simplify the complex fluid behavior. However, they seemed not to consider sufficiently and actually the behavior of the meniscus, ink behavior at the nozzle. This study focuses on the analysis of the behavior of meniscus to evaluate the given driving signal and to optimize that signal. The one-dimensional analysis was used to simulate the behavior of the ink from restrictor to the rear part of the nozzle.

The full three-dimensional analysis was used to evaluate the behavior of meniscus in the vicinity of the nozzle. This study suggested the new method to combine the one-dimensional analysis and the three-dimensional analysis and to optimize the analysis.

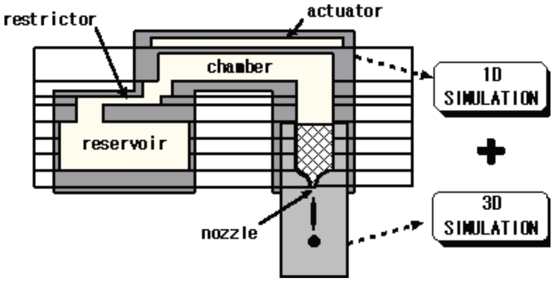


Figure 1. Structure of IJH

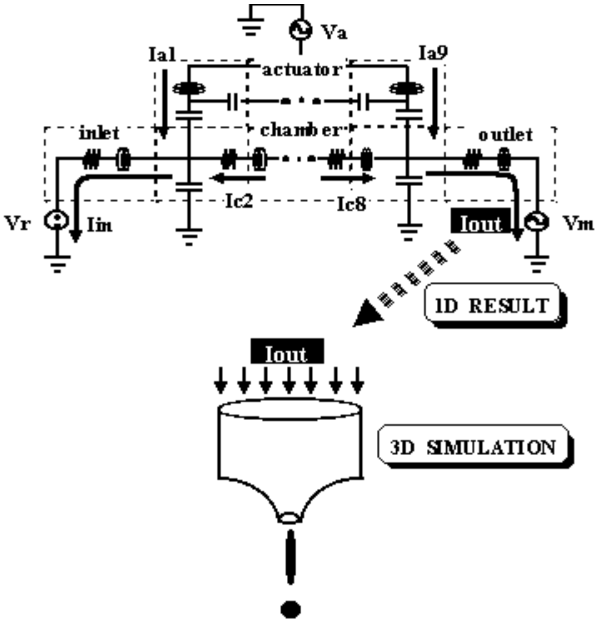


Figure 2. Model for 1D and 3D Simulation for 1D and 3D simulation

Modeling of Ink Jet Head

As shown in Fig.1, ink jet head, which is fabricated by bonding metal plates, consists of actuator, chamber restrictor, nozzle, flow channel and reservoir.

Fig. 2 shows that ink jet head is modeled as equivalent electric circuit and the three dimensional elements. The chamber and actuator is divided into 9 lumped elements for the more accurate modeling. To consider the effect of surface tension and contact angle in the vicinity of nozzle, we modeled the nozzle part as three-dimensional elements by FDM, not the lumped one-dimensional elements. Iout is the output of the one-dimensional analysis and input of the three-dimensional analysis in the front part of the nozzle. In Fig. 2, Vp represents the equivalent pressure of actuator generated by applied voltage on PZT. [Ca] and [Ma] are respectively the compliance matrix and the inertance matrix of actuator model. Rin and Min are respectively the resistance and the inertance of inlet, which consist of chamber element 1 and restrictor. Rc, Mc and Cc are respectively resistance, inertance and compliance of chamber element, which consist of chamber element 9, flow channel. Vr is the pressure of reservoir.

Actuator Modeling

Actuator is modeled as pressure source and lumped inertance-compliance system. We assumed that the equivalent pressure of the actuator is proportional to applied voltage on PZT. The pressure coefficient is defined as the ratio of the equivalent pressure to applied voltage on PZT. The equivalent pressure of the actuator is the product of pressure coefficient and applied voltage on PZT. The pressure coefficient can be obtained by ANSYS like the reference 7.

Fluid and Three-dimensional Element Modeling

The governing equation of the fluid elements can be derived as Eq. (1)

$$p = Rq + M\,dq/dt \qquad (1)$$

where, p is pressure drop in the lumped element [Pa] and q is flow rate in the lumped element [m^3/s]. If the pressure is given by p=P exp(2πf t), flow rate at the steady state can be solved from equation (2).

$$Qe^{j(2\pi ft+\varphi)} = \frac{Pe^{j2\pi ft}}{R + j2\pi fM} \qquad (2)$$

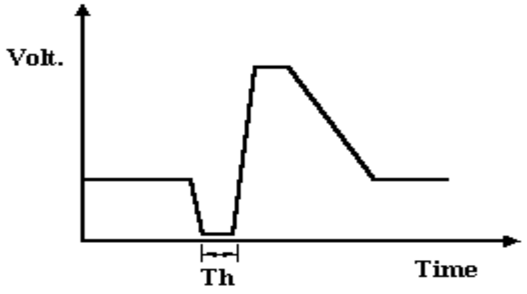
where, Q is the amplitude of flow rate, φ is phase angle and f is the frequency of excitation.

From equation (2), we can see that phase angle is zero at the low frequency and π/2 at the high frequency. Thus frequency should depend on phase angle. And resistance and inertance can be obtained as below.

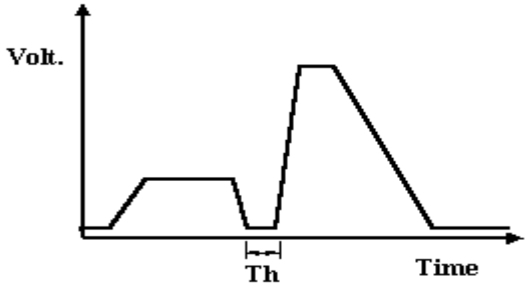
$$R = P/Q \qquad (3\text{-}1)$$

$$M = P/(2\pi fQ) \qquad (3\text{-}2)$$

By the method illustrated above, we calculated the resistance and inertance of inlet, chamber and outlet. The software for flow analysis, Flow-3D, was used for calculation of flow rate. The calculated R and M by Flow-3D were applied to the one-dimensional model. From restrictor or inlet to nozzle or outlet, the ink jet devices was simulated by the one-dimensional approach. However, the effects of contact angle and surface tension was not considered in the one-dimensional approach. To describe the ejection phenomenon of the droplet, we modeled the vicinity of the nozzle as three-dimensional mesh by FDM, with the effects of contact angle and surface tension considered. The output of the one-dimensional approach was applied to the input of the three-dimensional approach in this study.



(a) Real pull signal



(b) Double shot signal

Fig.3. Driving signals

Case Study

The Parameter Study of Driving Signal

The driving signals were shown in Fig. 3. The effective parameter of the signal was holding time(Th). This study dealed in only those parameters. The performance of ink jet head was calculated about the 4 cases of Th in each signal. The values of the simulation were not same to those of experiments, but the trends of both results were similar. The trends of the one-dimensional analysis have the differences with those of the three-dimensional analysis and the experiments in the field of the droplet size. It is because that one-dimensional analysis did not consider the surface tension and contact angle of the meniscus in the vicinity of the nozzle. These results show the importance of the meniscus behavior in the vicinity of the nozzle and the effectiveness of this study. This study explain that the holding time has the optimal point, and the real driving signal of the experiment was easily obtained by that result.

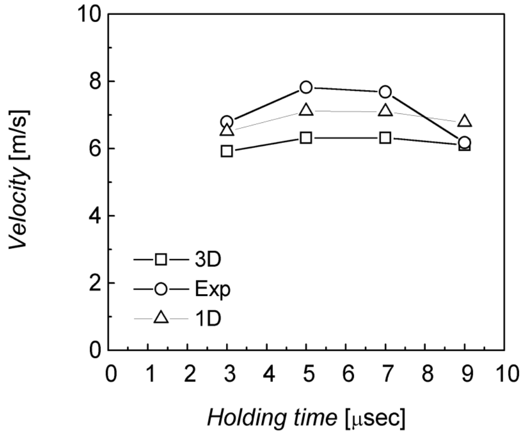


Figure 4. Velocity of droplet under real pull signal

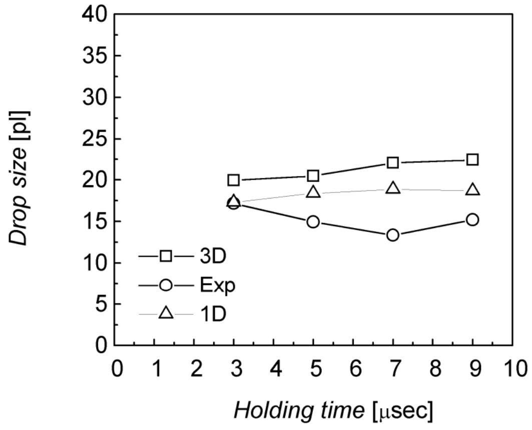


Figure 5. Size of droplet under real pull signal

Realization of Double Shot

The design of the driving signal focused on the modulation of the droplet size by the realization of double shot. This test enables the head to shot the droplets in the various sizes without any variation of the head structure. Besides, the range of the various sizes depend on the shape of the inner head structure. The theoretical approach can save the time and optimize the efficiency of the parameter study because of the difficulties and limits of the experimental approach.

To obtain the double shot, we designed the driving signal in Fig 3(b). The first pulling voltage has a great influence on the state of the droplet, and we interested in the first pulling voltage. The velocity and size of the droplet was proportional to the pulling voltage in Fig.8 and 9. In case of the lower limit of the pulling voltage(13V in table 1), the size of the droplet was 80% compared with that of the double shot in Fig. 9 and table 1. We verified the shape of signal played the key role in determining the size of the droplet in the theoretical approach compared with the experimental approach.

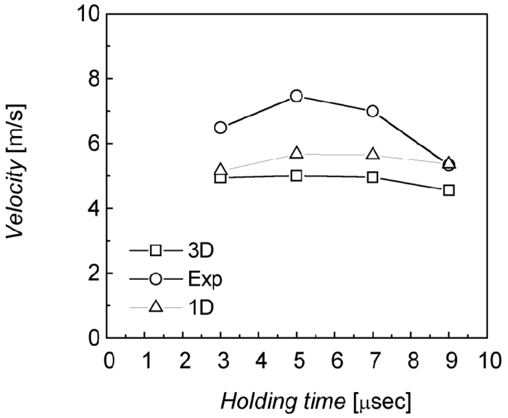


Figure 6. Velocity of droplet under double shot signal

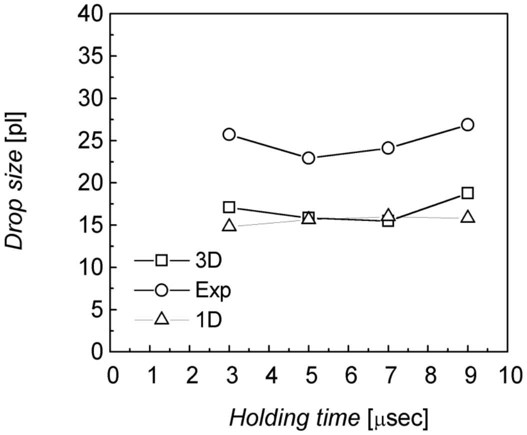


Figure 7. Droplet size under double shot

Table. 1 Drop sizes with Pulling Voltages

Pulling Voltage	Experiment	3D	1D
13V	16.7 pl	15.5 pl	16.0 pl
25V	27.6 pl	19.7 pl	16.3 pl

The result of the one-dimensional approach could not explain the phenomenon of the double shot in table 1, while that of the three-dimensional approach could describe the phenomenon like Fig. 10, 11, 12 and table 1. We could get the similar trend of the drop ejection between experiment in Fig. 10 and the three-dimensional analysis in Fig. 11. Figure 12 explained ejecting phenomenon of the real pull shot.

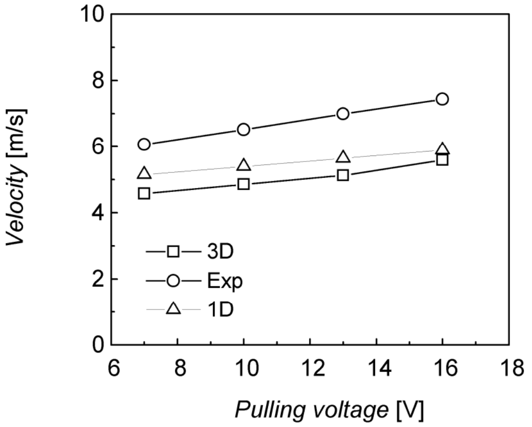


Figure 8. Droplet velocity under double shot

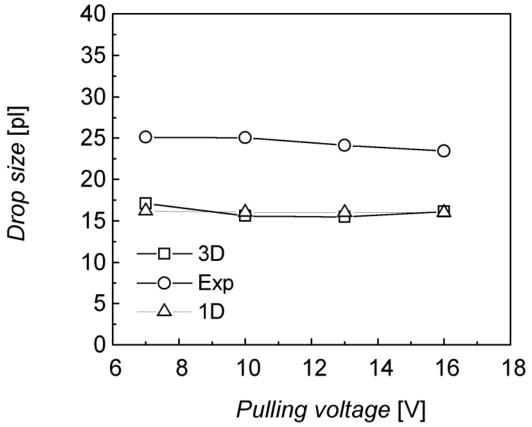


Figure 9. Size of droplet under double shot

Conclusions

This study suggested the new approach to predict the velocity and size of the droplet by the theoretical approach. To optimize the approach, we combined the lumped one-dimensional method and the full three-dimensional method. This approach is compared with the experiment and verified by the parameter study about the shape of signal. This approach depicted that there are optimal values in the parameter of the driving signal and the signal to consist the double shot.

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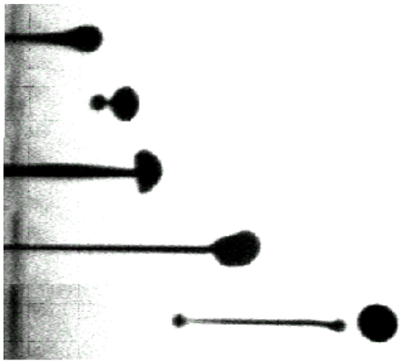

Fig.10 droplet ejection of experiment under double shot

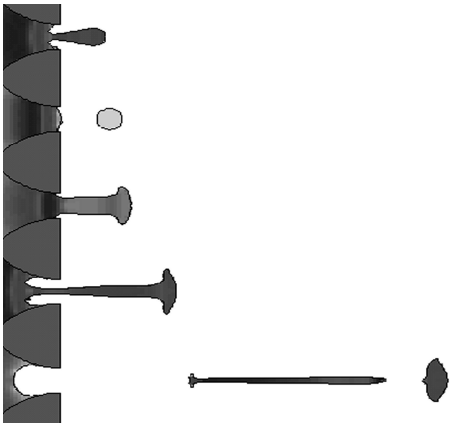

Fig.11 droplet ejection of simulation under double shot signal

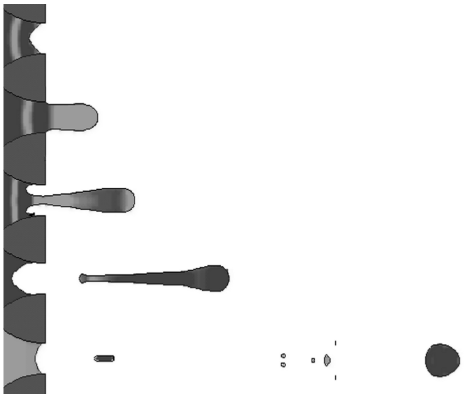

Fig.12 droplet ejection of simulation under real pull signal