A Study on the Improvement of the Performance in Ink Jet Head

Sung-Cheon Jung, Hyun-Suk Jang, Jung-Hwa Lee, Byung-Soo Kim and Kwang-Gyun Jang
Samsung Electromechanics Co., Korea

Abstract

The analytical study of the ink-jet head(IJH) may be applied to design IJH efficiently and optimally. This study presents the theoretical approach to design IJH. The mechanical system of IJH is simply designed to electric circuit with inertance, resistance and compliance, IJH that is composed of actuator, chamber, reservoir, restrictor, and nozzle including ink. The voltage and current in the circuit represent the pressure and velocity in the mechanical system, and therefore the size and velocity of the droplet can be calculated easily to design the structure of IJH, the shape of the driving signal and so on. Since there are many kinds of variables such as the material properties of ink and actuator and geometric values of the IJH, the material properties of ink are primarily defined to the values of the commercial ink of the ink-jet printer. The performance of IJH depends on the various factors, but this study concentrates not only on the resistance ratio and inertance ratio between restrictor and nozzle, but also the width of the PZT actuator. These variables have a great influence on the performance. To realize the theoretical approach more accurately, this study shows new methods.

Introduction

The concept of ink-drops-on-demand emerged indepen-dently in different structures in 1970 by Kyser, Zoltan and Stemme. At the same time, theoretical approach has been developed to design ink jet head. 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. To simulate and design ink jet head by lumped model, it is very important to design lumped parameters or model accurately. In this paper, the new calculation method of lumped parameters is suggested and ink jet head is simulated for the 5 cases of the widths of PZT actuator and 3 cases of restrictor sizes.

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.

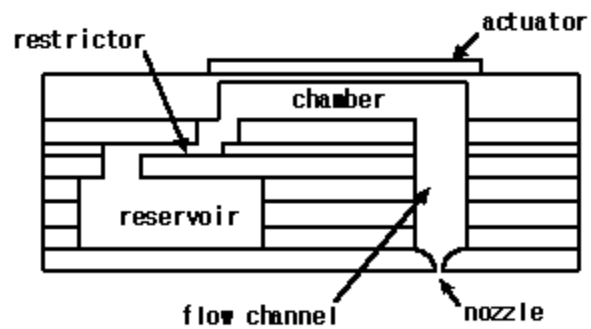


Figure 1. Structure of Ink Jet Head

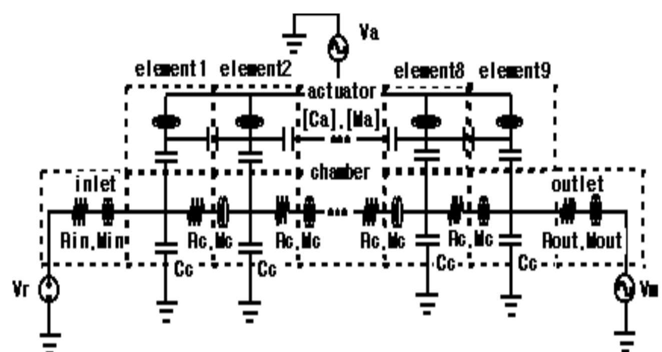


Figure 2. Equivalent Electric Circuit Model of head

Fig. 2 shows that ink jet head is modeled as equivalent electric circuit. The chamber and actuator is divided into 9 lumped elements for the more accurate modeling. 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. Rout and Mout are respectively those of outlet, which consist of chamber element 9, flow channel and nozzle. Rc, Mc and Cc are respectively resistance, inertance and compliance of chamber element. Vr is the pressure of reservoir and Vm is the meniscus pressure.

Actuator Modeling

Actuator is modeled as pressure source and lumed iner-tance-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 product of pressure coefficient and applied voltage on PZT. The pressure coefficient can be obtained by ANSYS like the following procedure:

1) Calculate the displacement of actuator with arbitrary pressure load.
2) Calculate volume change from the displacement result of step 1.
3) Obtain compliance of actuator by dividing applied pressure by calculated volume change.
4) Calculate the displacement of actuator with unit voltage applied on PZT.
5) Calculate the volume change from the displacement result of step 4.
6) Obtain the pressure coefficient by dividing calculated volume change in step 5 by compliance of actuator.

Ca[i,j], element of Compliance matrix of Actuator, has the same concept as flexibility influence coefficient in mechanical vibration. Thus Ca[i,j] is defined as the changed volume at i-th actuator element when unit pressure is applied on j-th actuator element. Since actuator has 9 lumped element, compliance matrix of actuator can be obtained by structural analysis of actuator with 9 different pressure loads.

Inertance of actuator can be derived from the differential equation of plate vibration like the following.

$$Ma(i) = \frac{1}{A_i^2} \iint_{element\, i} m(x,y)w(x,y)dA \qquad (1)$$

where, Ai is area of actuator element i, m(x,y) is density of unit area and w(x,y) is normalized displacement of actuator.

Fluid Modeling

The differential equation governing a lumped element of fluid with resistance and inertance can be derived as Eq. (2)

$$p = Rq + M\, dq/dt \qquad (2)$$

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).

$$Qe^{j(2\pi ft+\varphi)} = \frac{Pe^{j2\pi ft}}{R + j2\pi fM} \qquad (3)$$

where Q is amplitude of flow rate, ϕ is phase angle and f is frequency of excitation. The first term of denominator is dominant at the low frequency, while the second term is dominant at the high frequency. Thus equation (3) can be reduced to two approximated form as follows.

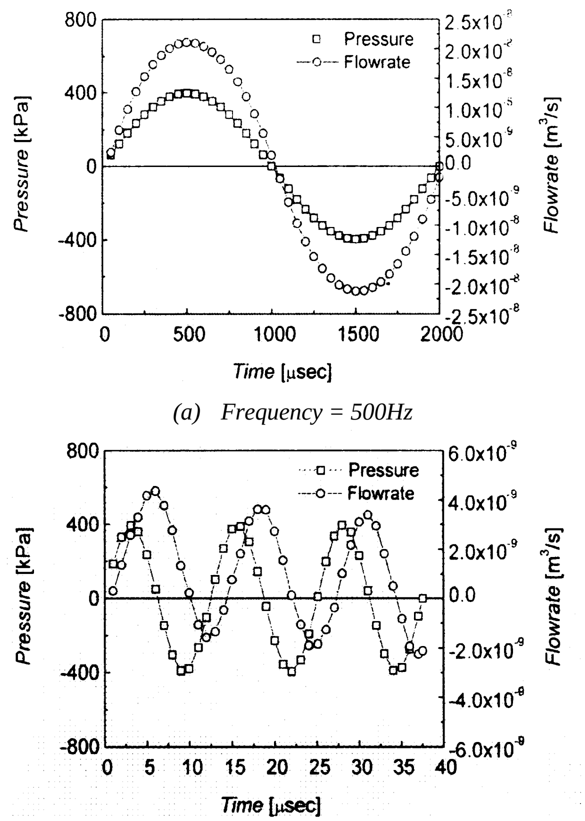
$$Qe^{j(2\pi ft+\varphi)} = \frac{Pe^{j2\pi ft}}{R} \quad \text{At the low frequency} \qquad (4\text{-}1)$$

$$Qe^{j(2\pi ft+\varphi)} = \frac{Pe^{j(2\pi ft-\pi/2)}}{2\pi fM} \quad \text{At the high frequency} \qquad (4\text{-}2)$$

From equations (4) and Fig. 4, 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.

$$R = P/Q \qquad (5\text{-}1)$$

$$M = P/(2\pi fQ) \qquad (5\text{-}2)$$



(a) Frequency = 500Hz

(b) Frequency = 80kHz

Figure 3. Pressure and Flow rate of inlet

By the method illustrated above, we calculated the resistance and inertance of inlet, chamber and outlet. The software of flow analysis, Flow-3D, was used for calculation of flow rate. Figure 3 shows the results in the inlet. As expected, phase angle is zero at the low frequency (500Hz) and π/2 at the high frequency (80kHz). Resistance and inertance of nozzle and restrictor are summarized in Table 1.

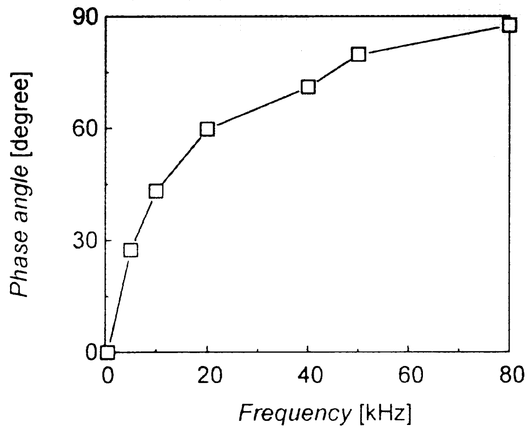


Figure 4. Variation of phase angle with frequency

Case Study

The Width of PZT Actuator

The performance of ink jet head was calculated for the 5 cases of the widths of PZT actuator. The width of chamber is 300 µm and that of PZT is varied from 200 µm to 240 µm. Figure 5 shows the pressure coefficient and drop velocity. As shown in Fig. 5, the wider PZT width is necessary for the improvement of head performance. But if PZT width becomes wide, alignment error may misalign the PZT actuator out of chamber. When the width of the PZT is designed, alignment error should be considered.

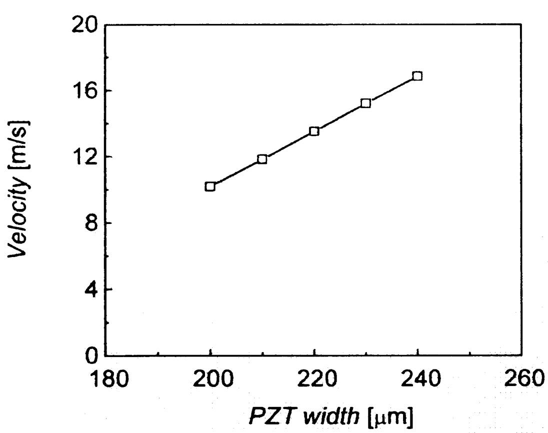


Figure 5. Drop velocity for 5 cases of the widths of PZT actuator

The Size of Restrictor

The performance of ink jet head was calculated for the 3 cases of restrictors. Resistance and inertance of inlet for 3 cases was calculated by the method illustrated above and was shown in Table 1. In case of 90X340 and 90X50, resistance and inertance of inlet are reduced 39% and 46% respectively while length is reduced 74%. It is because that the shape of inlet between reservoir and restrictor may have more influence on the variation of the inertance and resistance than length of restrictor.

Table 1. Inertance and Resistance of Nozzle and Inlet

	Dimension	Inertance	Resistance
Nozzle Diameter	28 µm	2.03e7	3.42e13
Restrictor Width x Length	90 x 340	2.63e8	1.88e13
	90 x 50	1.42e8	1.14e13
	200 x 400	6.64e7	1.18e12

Figure 6 shows the drop velocity and volume for the 3 cases of restrictor. From the result, as inertance and resistance of Inlet are reduced, drop velocity is increased and volume is reduced.

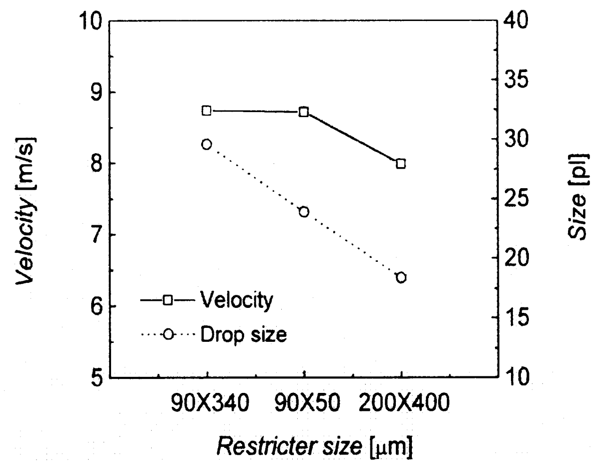


Figure 6. Drop velocity and size for the 3 cases of restrictor

Conclusions

Ink jet head was modeled as equivalent electric circuit. New method is suggested to calculate equivalent pressure of actuator and inertance and resistance of fluid. The performance of ink jet head was simulated for the 5 cases of the widths of PZT actuator and 3 cases of restrictors. Drop velocity is increased as the width of the PZT actuator becomes wide and resistance and inertance of restrictor are reduced. But it may be necessary to verify the simulation result by experiment for the accuracy of the model.

References

1. Kyser, E. L. and S. B. Sears, U. S. Pat. 3,940,398
2. Zoltan, S. J. , U. S. Pat. 3,683,212
3. Stemme, N., U. S. Pat. 3,747,120
4. Beasley, J. D., Model for Fluid Ejection and Refill in an Impulse Drive Jet, *Photogr. Sci. Eng.*, **21**, 78-82, 1997
5. Kyser, E.L., Collins, L.F., and Herbert, N., Design of an Impulse Ink Jet, *J. of Applied Photogr. Eng.*, **7**, 73-79, 1981
6. Meirovitch, ANALYTICAL METHODS IN VIBRATIONS, MACMILLAN