Acoustic Analyses on Oscillatory Behaviors in Piezoelectric Ink Jet Printhead

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Abstract

Periodic behaviors in a piezoelectric line ink jet printhead are studied. The printhead is composed of a monolithic structure having resolution of 600dpi in 4.25 inch effective print width. The structure is made up of plural metal foil layers, in which parts of channels are formed respectively, and actuator units mounted on top of them. The nozzles opened in the bottom layer are lead from cavities underneath of the actuator units through a descendant conduit named descender. Analyses on experiments suggest that a descender, cavity and unimorph actuator could make an individual acoustic element, of which acoustic period is much shorter than that oft the discharging unit.

Introduction

The authors have developed a piezoelectric line inkjet printhead. (1) It realized fast single pass printing with graphic quality by fairly compact structure as referred in Table 1. The appearance is shown in figure 1.

Table 1. Primary specifications of printhead

1. Dimension	158(w) x 25(d) x 60(h) mm
2. Number of Nozzles	2,656 nozzles per head
3. Print width	108 mm (4.25 inches)
4. Resolution	600dpi (in print width direction)
5. Drive frequency	Up to 20 kHz

Figure1. Appearance of Line Ink Jet Printhead

The printhead owes much of its capability to a dense arrangement of the discharging units, each of which consists of a unimorph actuator and individual channel branched from a manifold. The actuator, functioning as a diaphragm, is one of 664 included in the actuator unit. As shown in figure 2, an individual channel includes a restrictor, cavity, supply hole, nozzle and conduit between cavity and nozzle named descender.

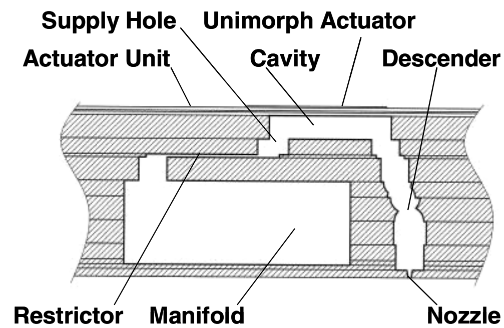

Figure 2. Cross Sectional View of Discharging Unit

The dense arrangement requires a compliant unimorph actuator that could generate a large deformation in spite of reduction of the cavity size, though its residual vibration could suffer jetting stability. (2)(3) In addition, this design lengthens the descender more due to a thick manifold that assures sufficient liquid supply. It implies that a descender could be another compliant element for its volume. (4)

However, the effect of a descender is usually neglected to predict an acoustic period of a discharging unit. Hence, this paper treats effects of a descender length as well as cavity depth on jetting phenomena in terms of acoustics.

Experimental Details

Experimental Setups

In order to analyze acoustic characteristics of a discharging unit, the amplitude of oscillations at an actuator and meniscus in a nozzle are measured on printheads filled with an aqueous ink, of which viscosity is 3.5 mPa*s at 25 centigrade. Actuator resonances are identified as frequencies of current peaks increased by applying a periodic driving signal swept across a frequency range from 30 to 700 kHz. The magnitude of the signal was adjusted so that drop ejection could not occur during the measurement. In case of the meniscus resonance, Laser Doppler Oscillation Analyzer is used to pick up meniscus velocity while the actuator is driven in a similar way as described above. Frequencies at peaks of oscillatory velocity are regarded as resonances. Figure 3 shows schematic expressions of the experimental setups for the measurements. And, figure 4 shows an example of a trend of amplitude in meniscus oscillation velocity observed on a printhead by using the equipment above.

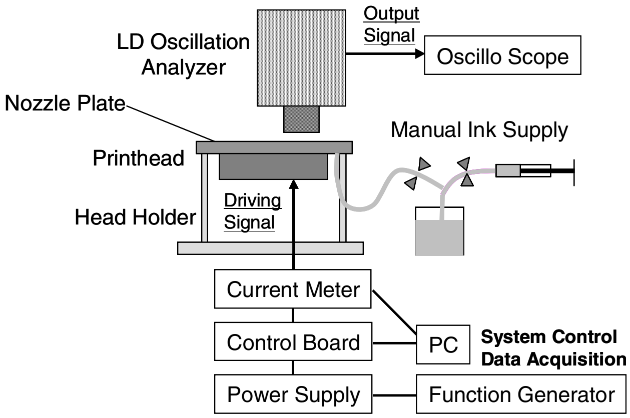

Figure 3. Schematic expression of experimental setup for measuring actuator and meniscus resonances.

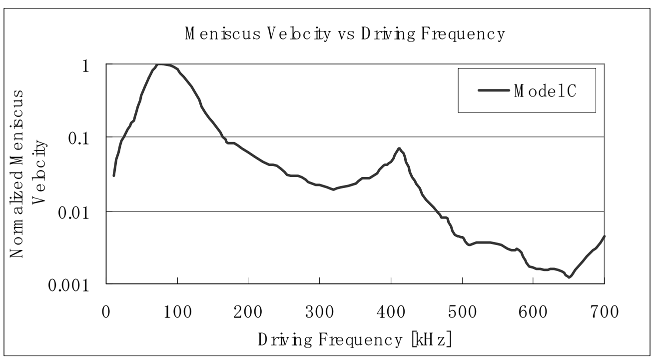

Figure 4. Amplitude profile in meniscus oscillation velocity.

Drop Velocity Profiles

A drop ejection is made by a volume change in a cavity caused by switching of a standby voltage applied to an actuator as shown in figure 4. A drop velocity profile like the one shown in Figure 5 is made to predict acoustic characteristics of the discharging unit.

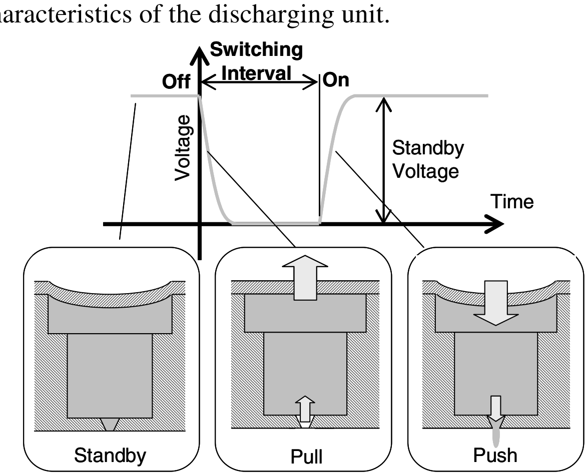

Figure 5. Schematic expression of a working discharging unit by applying a driving signal.

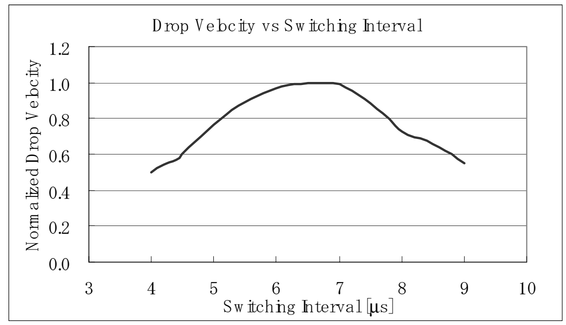

Figure 6. Drop velocity profile against switching interval.

Test Sample Design

The printhead models listed in table 2 were examined. These were manufactured by adjusting number of laminated layers or thickness of each layer.

Table 2. Dimensions list of examined printheads

Model	Normalized Cavity Depth	Normalized Length of Descendant Part
A	0.5	1.0
B	0.8	1.0
C	1.0	1.0
D	1.5	1.0
E	1.0	0.82
F	1.0	1.18
G	1.0	1.31

Results and Discussion

Acoustic Resonances

Generally, all the printheads have primary peaks around 70 - 80 kHz fairly consistently in spite of their differences in structure. However, the second peaks spread more widely from 328 to 469 kHz. There are more peaks exceeding 600 kHz but neglected in this paper because of their subtleness.

Similar resonances to the second ones are measured on actuators of the same discharging units although the primary peaks were not observed. It implies that oscillations of the ink filled in an individual channel are dominant in the primary resonances whereas the second resonance is an oscillation mode in which actuators play a more important role. These results are summarized in table 3.

Table 3. Measured resonances

Model	Meniscus Resonance (kHz)		Actuator Resonance (kHz)
	Fr_{M1}	Fr_{M2}	Fr_A

A	76	358	355
B	71	397	388
C	76	407	408
D	69	430	422
E	74	469	477
F	70	371	367
G	71	328	330

Acoustic analyses

The inverse of primary resonance observed in a meniscus can be regarded as an acoustic period of the discharging unit. It is generally defined as equation (1). [3] Also, a switching interval at the velocity peak could be one half of the acoustic period although it might have been less accurate because of influences from higher resonances. Both of the results are summarized in table 4.

$$T_C = 2\pi\sqrt{\left(\frac{M_n \cdot M_r}{M_n + M_r}\right)\cdot\left(C_a + C_c\right)} \qquad (1)$$

T_C: Acoustic period of a discharging unit
M_n, M_r: Acoustic inertance of a nozzle and restrictor
C_a, C_c: Acoustic compliance of an actuator and cavity

Table 4. Acoustic periods obtained by experiments and theory

	Acoustic Period (μs)		
Printhead Model	**Oscillation Period**	**Drop Velocity Peak x 2**	**Equation (1)**
A	13.1	13.2	10.1
B	14.0	12.2	10.7
C	13.2	12.4	11.1
D	14.4	14.4	11.9
E	13.5	10.6	11.1
F	14.3	12.8	11.1
G	14.1	13.8	11.1

According to equation (1), an acoustic period could become shorter as a cavity becomes thinner due to a decrease in compliance that depends upon its volume. However, the both experimental results suggest that inertance of a cavity, which is increased by a narrow cross section, could have extended an acoustic period, although it is neglected in equation (1). In addition, experimental results suggest that effect of long descender should be taken into account. Having examined several acoustic models to explain the phenomena, we have chosen the one expressed as an equation (2), in which compliances of a descender, supply hole, and cavity inertance are involved. Especially, a cavity inertance is divided into supply and nozzle directions to be added on that of a restrictor and nozzle respectively.

$$T_C = 2\pi\sqrt{\left(\frac{M'_n \cdot M'_r}{M'_n + M'_r}\right)\cdot\left(C_a + C_c + C_s + C_d\right)} \qquad (2)$$

$$M'_n = M_n + M_c/2$$
$$M'_r = M_r + M_c/2$$

M_c: Acoustic inertance of a cavity
C_s, C_d: Acoustic compliance of a supply hole and descender

Also, as to the second resonance, we have established an acoustic model expressed as equation (3). As shown in the equation, we suppose that the second resonance is an oscillation mode caused by a compliant actuator and descender in relatively broad conduits of an individual channel.

$$T_S = 2\pi\sqrt{\left(\frac{M_d \times (M_c + M_s)}{M_d + M_c + M_s} + M_a\right)\cdot\frac{C_d \times C_a}{C_d + C_a}} \qquad (3)$$

T_S: Acoustic period of the second resonance
M_d: M_a, M_s: Acoustic inertance of a descender, actuator and supply hole

Figure 7 - 10 show comparisons of acoustic periods obtained by the meniscus observation, equation (1), (2) and (3). Fairly good correlation with the experimental results are demonstrated by them.

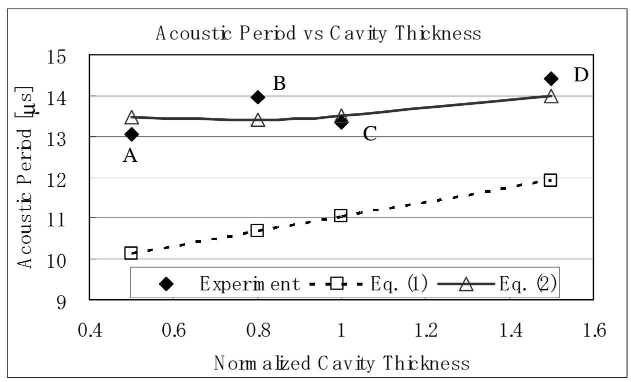

Figure 7. Comparisons of cavity depth effect on acoustic period expressed by equation (1) and (2).

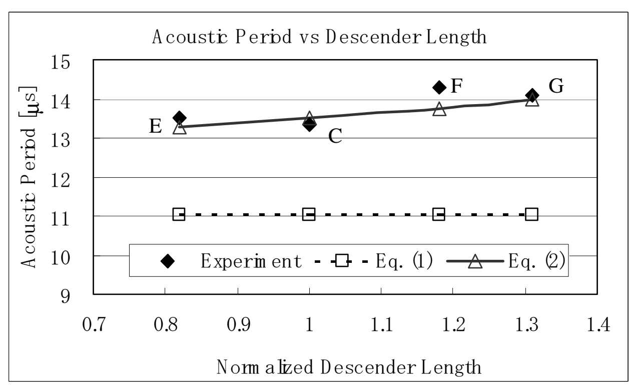

Figure 8. Comparisons of descender length effect on acoustic period expressed by equation (1) and (2).

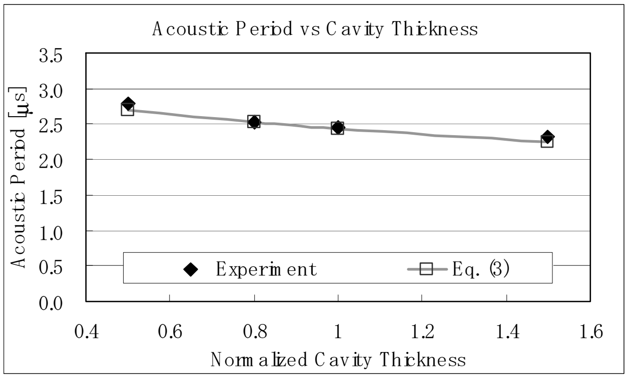

Figure 9. Cavity depth effect on the second acoustic period expressed by equation (3).

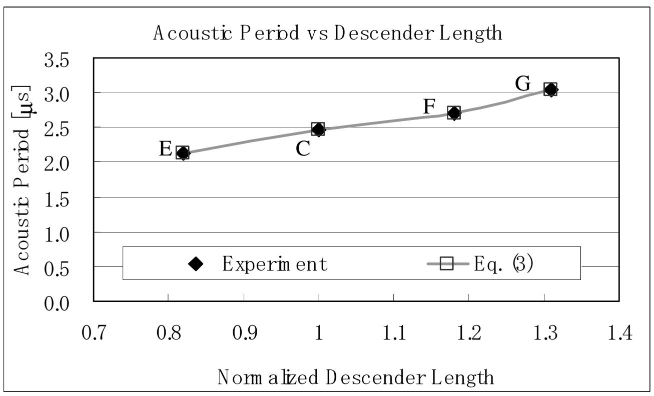

Figure 10. Descender length effect on the second acoustic period expressed by equation (3).

Drop velocity peaks

From a theoretical view point, a drop velocity is maximized at a switching interval corresponding to a half of the primary acoustic period. However, in several cases, it is rather close to 2.5 times the second acoustic period in which residual oscillations of the second mode in opposite phases caused by each switching is synchronized. In these cases, it is supposed that oscillations of the primary mode are supplemented by the second.

Switching intervals at velocity peaks are summarized in table 5 with their expectations on the primary and second acoustic periods, in which numbers with underline are relatively dominant mode to the velocity peaks because of their closeness to the observation. These results imply that a higher resonance could be influential on a drop velocity in addition to the primary mode.

Table 5. Switching intervals at drop velocity peaks compared to the prospects on resonances

	Drop Velocity Peak Timing (µs)		
Printhead Model	**Primary Res. Period x 0.5**	**2nd Res. Period x 2.5**	**Drop Velocity Observation**
A	<u>6.6</u>	7.0	6.6
B	7.0	<u>6.3</u>	6.1
C	6.6	<u>6.1</u>	6.2
D	<u>7.2</u>	5.8	7.2
E	6.8	<u>5.3</u>	5.3
F	7.2	<u>6.7</u>	6.4
G	<u>7.1</u>	7.6	6.9

Conclusion

Oscillatory behaviors in a piezoelectric ink jet printhead are observed. The results suggest that a descender compliance and cavity inertance could have influence on an acoustic period of discharging unit.

Acoustic models are proposed for the primary and second acoustic resonances of a piezoelectric ink jet printhead with a long descender, compliant diaphragm and thin cavity. The models showed good accordance with above experiments.

Higher resonances could be influential in addition to the primary mode to the drop velocity.

References

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Author Biography

Shin Ishikura joined Kyocera Corporation in 1995. Since then, he has been in development section for printheads and their components. He received his degrees of M.S. and M.Eng. from Liverpool John Moores University and Kanazawa University respectively.

Manabu Hibi received his B.S. degree in mechanical engineering from Keio University (1988). In 1988, he joined Brother Industries, Ltd., where he's consistently been engaged in the support of CAE. He started his carrier as an inkjet head designer since 2001.