Design Studies on Ink Jet Printhead to Improve its Throughput

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Abstract

Kyocera has introduced aqueous ink jet printhead suitable for high speed single pass printing by making use of 2,656 nozzles aligned in 108 mm, from which 12 pl drop can be ejected at 30 kHz. In order to improve their productivity, the authors have been studying on the design through the steps as follows.

Firstly, acoustic period of a drop ejector is shortened by reduction in pressurizing cavity area, or bend mode actuator compliance. This modification worked as intended but made the drop ejection speed slower due to decrease in cavity volume deformation. In order to compensate the pressure fall, drive voltage rise to 109% of original design.

Secondly, for higher flow rate inside the manifold, they are expanded in cross sectional area, not in their thickness but by their depth particularly, or dimension in perpendicular direction to print width horizontally. It is due to restriction for the expansion in height, not to extend descender together that has influence on acoustic period. As a result, cross sectional area of the manifolds are increased 14 % from original design by 5 mm expansion of printhead dimension in depth.

By implementation of all these design changes, newly developed printhead can be driven up to 40 kHz with 12 pl drop from same number of nozzles as original model. In spite of 32% higher flow rate from the original model, the developed model show stable printing performance up to 1,680 mm/s

Introduction

Single-pass DOD ink jet technology has been adopted not only in transaction but in graphic print market by making use of its speed, operation cost and flexibility in system integration. Especially since DRUPA 2008, this trend has been accelerated. It is nothing special to print over 100 m/min linear speed with resolution over 600 dpi by DOD ink jet. Naturally, technical requirement for an ink jet print head that plays key roll to realize such performance is getting higher.

Since introduction of the first prototype model in 2005 at NIP 21, Kyocera has been studying to increase printing speed [1][2]. The original printhead realized single pass print at 847 mm/s with 600 dpi x 600 dpi resolution across 108 mm width by its unique design. Then, based upon the original technology, next commercialized model achieved 30 kHz or 1,270 mm/s in same print speed [3].

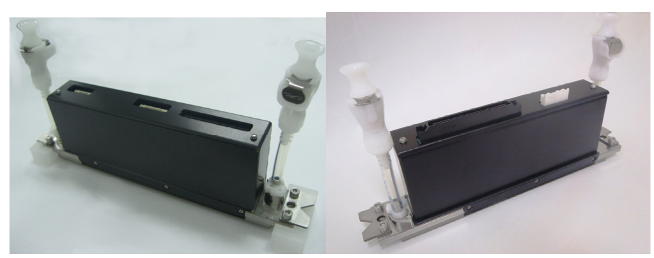
Based upon past studies, Kyocera has been making further improvement in print speed through approaches in two major aspects. The one is acoustic characteristics of a drop ejector. Its design and driving condition are modified to shorten the acoustic period. And, the other one is ink supply for each drop ejector operated at a higher frequency. In order to catch up increase in amount of ink flow in it, manifold is expanded to reduce its resistance. By combination of these modifications, new printhead realized 40 kHz operation or linear print speed of 1,693 mm/s.

Printhead Specifications

Following table shows comparison of conventional and latest models of Kyocera piezoelectric aqueous ink jet printhead KJ4 series. As shown in the table, latest model keeps original design concept. Of these specification, increase in drive voltage and expansion in depth are related to mechanisms to rise drive frequency from the original model. These mechanisms are to be discussed in the following section.

Table 1: Representative Specifications of the Print Head

	KJ4B-QA06NTB	KJ4B-YH06WST
1. Dimension (WxDxH)	200 mm x 25 mm x 59.3 mm	200 mm x 30 mm x 69.3 mm
2. Print width	108.25 mm (600 dpi)	
3. Nozzle No.	2,558 (600 dpi)	
4. Resolution	600dpi x 600 dpi	
5. Drop Volume	5, 7, 12 pl	
6. Max. Drive frequency	30 kHz	40 kHz
7. Suitable ink viscosity	5 - 6.5 mPa*s	
8. Drop velocity	7 - 8 m/s	8 - 9 m/s
9. Drive voltage	20 - 24 V	22 - 26 V



KJ4B-QA06NTB KJ4B-YH06WST

Figure 1 *Appearance of the printhead.*

Design studies

Drop ejector design

Figure 2 shows schematic cross sectional view of drop ejector of KJ4 series and equation (1) expresses its acoustic period in a drop ejector respectively. In case of bend mode print head like this, actuator can be the most dominant element to define its acoustic period because of its compliance (see table 2). Naturally, this study focuses on influence of cavity area that defines mechanical constraint on the actuator firstly [3][4].

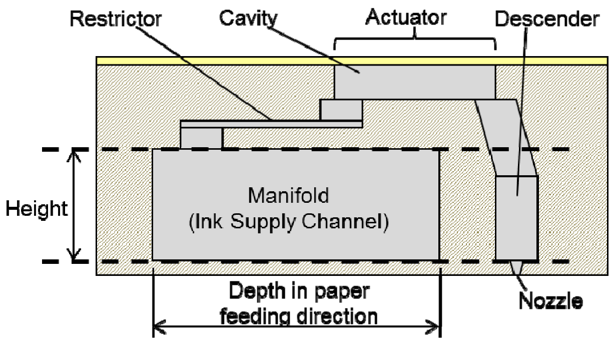


***Figure 2** Cross sectional view of drop ejector.*

$$T_C = 2\pi\sqrt{\left(\frac{M'_n \cdot M'_r}{M'_n + M'_r}\right)\cdot\left(C_a + C_c + C_s + C_d\right)}$$
$$M'_n = M_n + M_c/2 \qquad (1)$$
$$M'_r = M_r + M_c/2$$

T_C: Acoustic period of drop ejector
M_n: Acoustic inertance of nozzle
M_r: Acoustic inertance of restrictor
M_c: Acoustic inertance of cavity
C_a: Acoustic compliance of actuator
C_c: Acoustic compliance of cavity
C_s: Acoustic compliance between cavity and restrictor
C_d: Acoustic compliance of descender

Table 2: Compliance of each element in 30 kHz print head.

Actuator compliance	68.4%
Cavity compliance	12.7 %
Compliance between cavity and restrictor	3.1 %
Descender compliance	15.8 %

Figure 3 shows summary of actuator performance obtained by finite element method and acoustic calculation in the same way as the past studies [3][4]. The horizontal axis indicates relative cavity area to that of current 30 kHz print head. And, the vertical axis also indicates relative values to those of the 30 kHz model in acoustic period and the volume displacement dV compared to cavity volume V.

It is aimed to shorten acoustic period Tc to increase drive frequency by shrinkage in cavity area but relative volume displacement dV/V can be smaller at the same time. As a result, velocity of drops generated from a nozzle can be lower [5].

Therefore, it is intended to compensate jetting performance by increasing drive voltage 2V. According to the calculation summarized in figure 3, equivalent relative displacement dV/V can be obtained with 95.4% cavity area of the 30 kHz model. With this cavity area, acoustic period of the drop ejector is shortened to 95.0% of the original design, which is not linearly shrunken to the jetting period but still practically applicable range to 40 kHz operation.

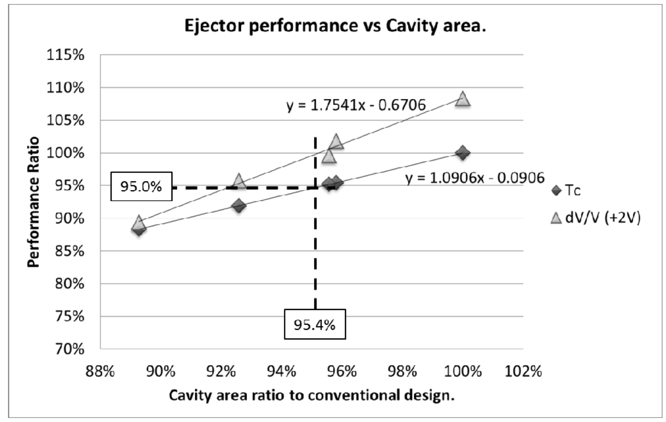


***Figure 3** Cross sectional view of drop ejector.*

Based upon discussion above, cavity area is shrunken and 40 kHz operation is realized. Changes in properties from 30 kHz model are summarized as follows.

Table 3: Modification from 30 kHz print head model.

Cavity area	95.4%
Actuator compliance	86.1%
Acoustic period	95.0%
Drive voltage	109.1%

Consideration on ink supply

In order to absorb 33.3% increase in flow rate inside a printhead by raising drive frequency from 30 to 40 kHz, it was considered to widen manifolds in their cross sectional area. However, there is physical restriction in their height since it makes descenders longer as shown in figure 2, which has negative influence on the drop unity. Figure 4 shows drop status of printheads, of which descender length are varied, at their velocity peaks by acoustic synchronization to their drop ejectors. As discussed in the past study, it is thought to be an acoustic phenomenon dependent on descender length.

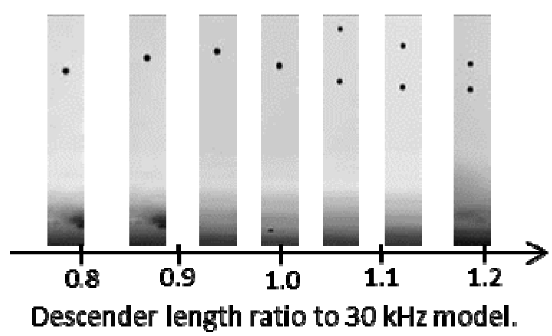


***Figure 4 Influence of** descender length on drop unity*

So, manifolds should be expanded in their depth or paper feeding direction but there also should be limit in the dimension because of practical use. Taking account of margin in flow rate with current 30 kHz model in terms of pressure loss through the manifold, it is decided to expand the cross sectional area 14% by its depth. According to equation (2), which is definition of pressure loss through a rectangular manifold, aspect ratio in its cross sectional shape and possible flow velocity through the expanded manifold, pressure loss can be 46% less than the original design at 40 kHz operation although it is 23% higher at operation of current model at 30 kHz. Results of the calculation are summarized in figure 5 as follows.

$$\Delta P = \lambda \times \frac{L}{d_e} \times \frac{\rho v^2}{2} \qquad (2)$$

ΔP: Pressure loss through a pipe
λ: Coefficient of pipe inside friction (fixed).
L: Length of the manifold (fixed).
d_e: Equivalent tube diameter (5.9% larger with 40 kHz model).
ρ: Density of fluid (fixed).
v: Averaged flow velocity (12.3% lower with 40 kHz model).

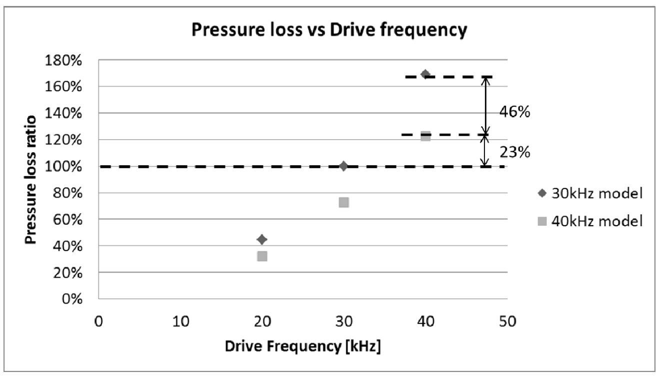


Figure 5 Effect of manifold expansion on pressure loss.

Jetting and Printing tests

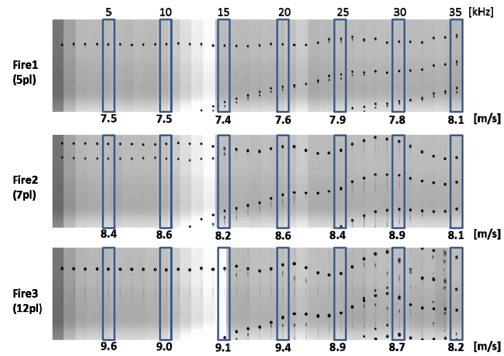
Jetting and Printing Performance

Figure 6 shows comparison of new print head to current 30 kHz model in jetting behavior against drive frequency. Also, figure 7 shows the comparison in dot status on plain paper coated with ink absorption layer. All these observations are made with optimized waveform for each jetting and print condition.

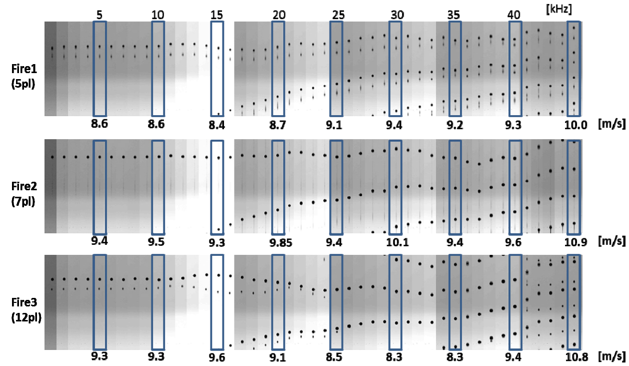
In case of the current model, satellites can be seen with 7pl up to 15 kHz although they are not clearly visible on the paper as dots shown in figure 5(a). And, 12pl drop is slowing over 30 kHz, which is practical limit of operation with this print head model.

Comparing with 30 kHz model, 40 kHz model shows less drop velocity variation through the entire operation frequency range. There is satellite with 5pl drop regardless of drive frequency, and with 12pl drops under 25 kHz. However, these are not clearly visible on the media as shown in figure 5(b).

As previously discussed, acoustic period of 40 kHz model is assumed to be 95% of that of the 30 kHz model but sufficient time could be taken for waveform of the maximum drop. Although satellites become clearer over 40 kHz, this printhead is practically applicable up to 40 kHz from view point of jetting quality.

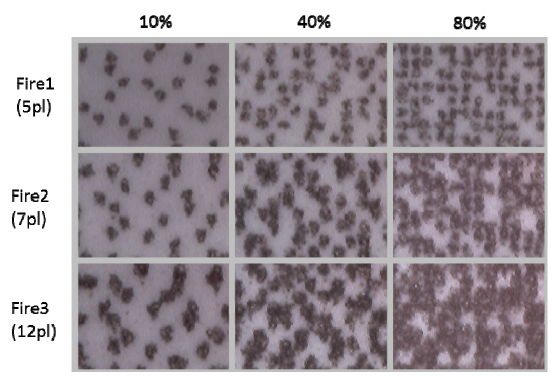


(a) Jetting behavior of 30 kHz model

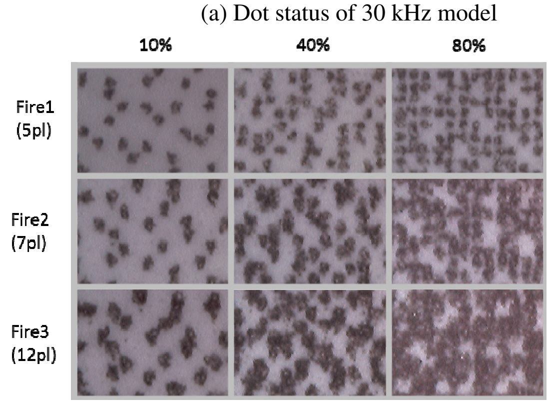


(b) Jetting behavior of 40 kHz model

Figure 6 Jetting behaviors against drive frequency.



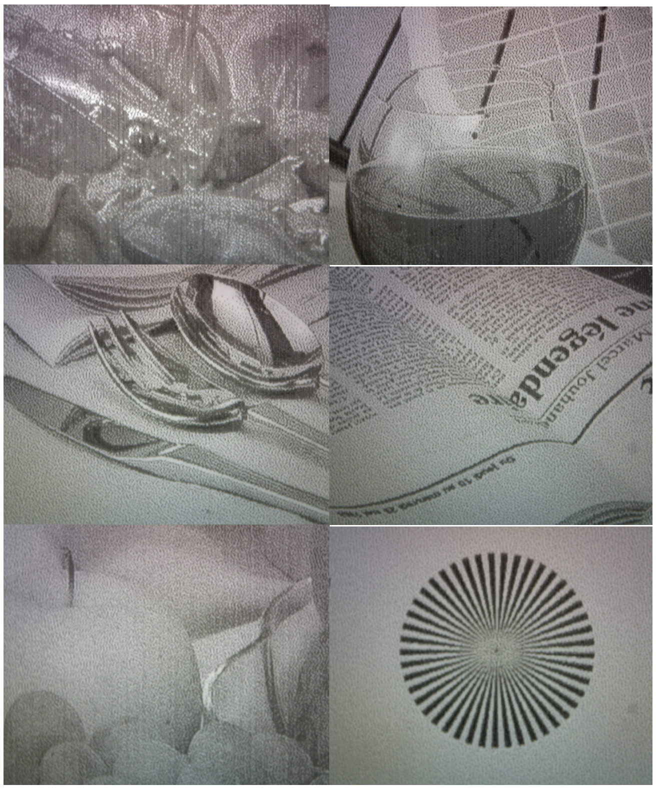
(a) Dot status of 30 kHz model



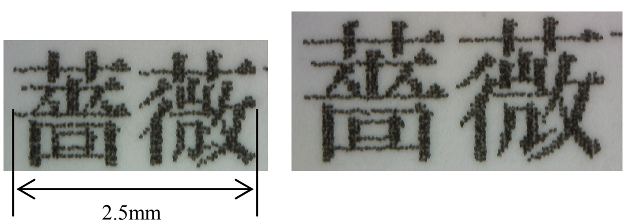
(b) Dot status of 40 kHz model

Figure 7 Magnified dots image.

Also, graphic images are printed with the new 40 kHz print head. Figure 8 shows representative magnified views of the prints. All these prints are parts of ISO image printed at 1,693 mm/s in 4 level grayscale 600 x 600 dpi only with black pigment ink on plain paper coated with ink absorption layer. In spite of the print speed faster than current 30 kHz model, equivalent image quality can be achieved with new print head.



(a) Magnified parts of ISO 400 image.



4pt 5pt

(b) Chinese letters.

Figure 8 Magnified views of print samples.

Conclusion

Drop ejection frequency of a piezoelectric ink jet printhead is raised from 30 kHz to 40 kHz, which made 33.3% improvement in printing productivity. It enables single pass print at 1,693.3 mm/s with 600 dpi x 600 dpi resolution with water based ink.

It is achieved by 4.7% shrinkage in cavity area from current 30 kHz model. Also, manifold is expanded 14% in its depth or paper feeding direction. As a result, ink supply is secured by 46% reduction in pressure loss through the manifold from current design for operation at 40 kHz.

Jetting performance of the printhead is verified up to 40 kHz by drop formation and dots quality on a paper media. It is also confirmed as image quality printed at 40 kHz or 1,693 mm/s in 600 x 600 dpi.

References

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Author Biography

Shin Ishikura joined Kyocera Corporation in 1995. Since then, he has been working for ink jet printhead and the related business development. He received his degrees of M.S. and M.Eng. from Liverpool John Moores University and Kanazawa University respectively.

Ayumu Matsumoto was given his B.Eng. degree in mechanical engineering from Kagoshima University in 1996. He joined Kyocera Corporation in 1998 and started his career as a print head designer in 2002.Since then, he has been playing key role in the development.

Ryota Imanishi received his M.Eng degree in mechanical engineering from Ritsumeikan University in 2008. Then, he joined Kyocera Corporation and have been working for production engineering, printhead evaluation and related business development.