Development of Ink Jet Printhead Equipped With a Large Monolithic Unimorph Piezoelectric Actuator Unit.

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Abstract

Kyocera realized a trapezoidal actuator unit with one inch width approximately, in which 664 portions of individual unimorph piezoelectric actuators are formed in matrix of 16 rows. This actuator unit has been used for its own piezoelectric ink jet printheads known as KJ4 series, in which four units are used to cover 4.25 inch (108.25 mm) print width.

Then, Kyocera has developed a larger actuator unit that covers 4.4 inch (112.35 mm) print width with monolithic rectangular body, in which numbers of individual active portions are arranged. And, it has been adopted for development of new ink jet printhead series.

As the first model of the new printhead series, 4.4 inch (112.35 mm), 300 npi ink jet printhead for aqueous ink is introduced. It is equipped with nozzles forming a matrix of 16 rows x 166 columns in 4.4 inch x 1 inch (112.35 mm x 25.4 mm) rectangular region. Each group of adjacent eight nozzle rows belongs to individual channel group, in which nozzles are arranged in 300 npi. And, independent driving conditions in voltage and waveform can be applied to each nozzle group. Practically, this printhead is intended to pack two pieces of 300 npi printheads in 200mm x 36mm x 61mm single body for downsizing and simplification in printer design especially for multi-pass printing applications.

Introduction

Since introduction of the first prototype single pass printhead in 2005 at NIP 21, Kyocera has been working on printheads over 4 inch swath. The original printhead realized single pass printing at 847 mm/s with 600 dpi x 600 dpi resolution across 108 mm [1]. Then, based upon the original technology, commercial model achieved 30 kHz or 1,270 mm/s [2]. It has been well adopted in high speed roll to roll printers mainly for transaction market.

Also, there has been another attempt to apply this platform to scanning printing for some industrial fields such as textile printing. Finally, printers using KJ4 reached equivalent productivity to conventional flat screen printers with much more flexibility for variety of products.

A wide printhead equipped with numbers of nozzles in high density, like KJ4, is an ideal solution in terms of productivity since it allows printing by the minimum times of scanning. However, a printhead optimized for single pass printing cannot be suitable for some multi pass applications because of drop generation rate. It can be excessive under certain condition and image sharpness can be ruined.

In case of multi pass printing, image quality is maintained by averaging variation of jetting performance of nozzles across print swath by printing a portion of image with different part of printhead. Also, it is benefit of multi pass printing to take time for ink to be fixed on or absorbed into a media in every scan, which prevents color mixture on media. Hence, nozzles should be arranged in less density than print resolution so that dots formed with each nozzle can be defined more clearly on a media in case of multi pass scanning printing.

Having considered technical benefit and market needs, we decided to develop a printhead for high-speed scanning application based upon current KJ4. It started as an attempt to divide a nozzle module of KJ4 for 600 npi single-color into the one for 300 npi double-color.

However, it did not work practically because of trapezoidal nozzle arrangement. Inks of different colors were mixed up on nozzle plane during wiping since they locate in overlapping position for wiping. Therefore, it is necessary to arrange nozzle rows of different colors in parallel without any overlapping across the print swath (figure 1).

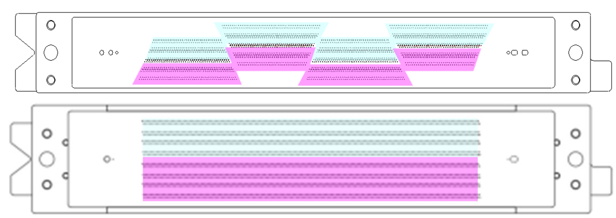


Figure 1 *Concept of nozzle arrangement.*

It brought structural changes. Firstly, it requires monolithic actuator unit, in which unimorph actuators corresponding to each nozzle are formed, to cover whole print swath. Secondly, manifold thickness is enlarged to provide sufficient ink across print swath. This paper covers these structural aspects of the new printhead and its performance in comparison with current KJ4.

Printhead Specifications

Following table 1 and figure 2 show comparison of 600 and latest 300 npi models of Kyocera KJ4 printhead.

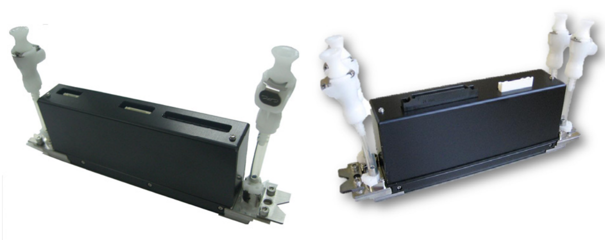
As shown in the table, there are structural changes. Firstly, depth, or dimension in scanning direction, of the printhead is expanded. It is partly because of a gap between regions of different colors to avoid color mixture on nozzle plate. Also, it is intended to reduce mechanical crosstalk between actuators by expanding distance among them.

Secondly, effective print swath is extended. It is realized by utilizing nozzles at both ends, which cannot be utilized in case of trapezoidal unit of original KJ4 [1]. Number of nozzles is increased in accordance with the swath.

Jetting characteristics of both models are equivalent practically although drive voltage range is higher. Drops up to 12, 18 pl are ejected at 30 and 20 kHz respectively.

Table 1: Representative Specifications of the Print Head

	KJ4B-QA06NTB	KJ4B-0300-006DS
1. Dimension (WxDxH)	200 mm x 25 mm x 59.3 mm	200 mm x 36 mm x 68.5 mm
2. Print swath	108.25 mm	112.35mm
3. No. of Nzl. per color	2,558	1,328
4. No. of Nzl. in print swath	2,558	2,656
5. Nzl density	600 npi	300 npi
6. No. of colors	1	2
7. Drop volume	5, 7, 12 and 18 pl	
8. Max. drive frequency	30 kHz with drop up to 12 pl 20 kHz with drop up to 18 pl	
9. Suitable ink viscosity	5 - 6.5 mPa*s	
10. Drop velocity	8 - 9 m/s	8 - 9 m/s
11. Drive voltage	20 - 24 V	24 - 28 V



KJ4B-QA06NTB KJ4B-0300-006DS

***Figure 2** Appearance of the printhead.*

Design studies

Front-end design

Figure 3 shows primary elements of 300 npi model. Basic concept of the printhead structure has been consistent from the 600 npi. It consists of electronics to control jetting function, back-end module that includes a reservoir to provide ink for each channel and front-end module, in which jetting functions are equipped. Front-end consists of channel module and actuator unit.

In case of 300 npi model, there are four times numbers of individual unimorph actuators in 27 x 112.35 mm region as shown in figure 4. And, there are four inlets at each end, from which ink is filled in straight manifold. Figure 5 shows comparison of ink supply in the front-end module with 600 npi mode. Actuators are aligned in straight 16 parallel rows across print width and drop ejectors are formed at corresponding position. Figure 6 shows cross-sectional view of drop ejector and manifold, how it is connected.

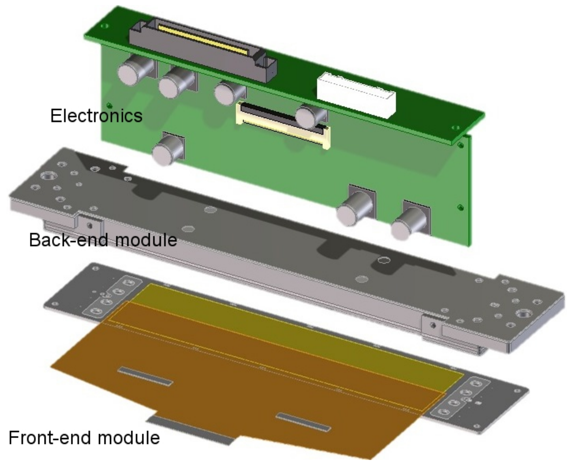


***Figure 3** Primary elements of the printhead.*

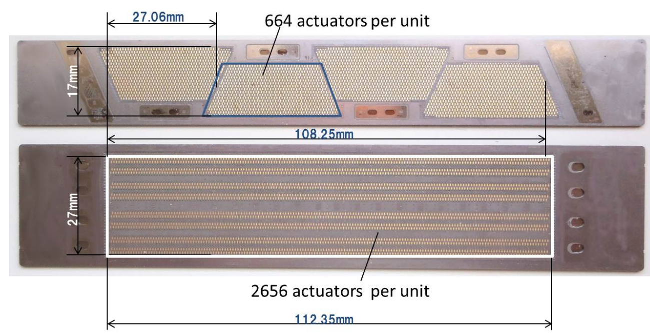
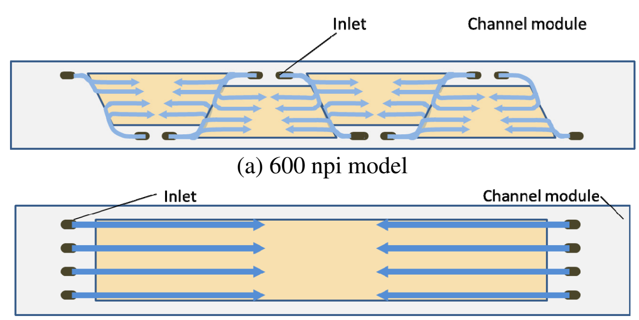


***Figure 4** Appearance of front-end module.(above: 600 npi/ below: 300 npi)*



(a) 600 npi model

(b) 300 npi model

***Figure 5** Ink supply through manifold*

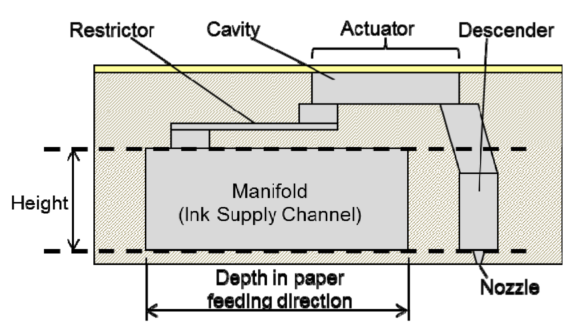


***Figure 6** Cross-sectional view of drop ejector*

Manifold design

In order to compensate pressure loss by the length in case of straight manifold across print swath, cross sectional area of the manifold should be expanded. However, there is physical restriction in their height since it makes descenders longer as shown, which has negative influence on the drop unity [3].

Ink is supplied through inlets located at each corner of trapezoidal area across the print swath in case of 600 npi model. The farthest drop ejector from an inlet is 0.5 inch apart, which is the center of one inch unit width. Whereas it is almost half of print swath, 2.2 inch approximately, in case of 300 npi model since inlets are located at both ends of manifolds. Therefore, distance to the farthest drop ejector from each inlet can be 4.4 times in case of 300 npi model compared to that of the 600 npi. In order to equalize the pressure loss, manifold depth should be 1.5 times wider than that of the 600 npi according to the equation (1).

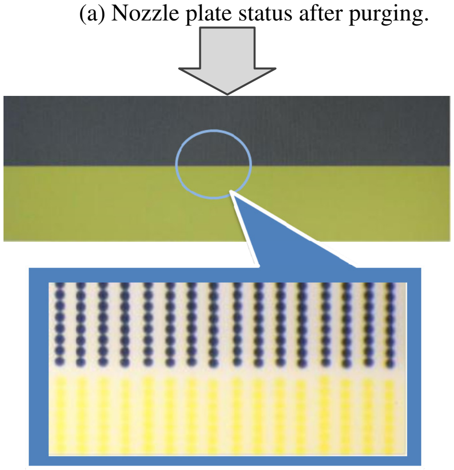
$$\Delta P = \lambda \times \frac{L}{d_e} \times \frac{\rho v^2}{2} \qquad (1)$$

ΔP: Pressure loss through a pipe
λ: Coefficient of pipe inside friction (fixed).
L: Length of the manifold.
d_e: Equivalent tube diameter.
ρ: Density of fluid.
v: Averaged flow velocity .

Features of printhead

Two color channels

(a) Nozzle plate status after purging.



(b) Print status.

Figure 7 *No color mixture by continuous printing after maintenance.*

As referred above, there is a gap between two groups of nozzles in the nozzle plane so that different colors of inks coming through them would not be mixed on it. In order to verify the design concept, maintenance test was taken place firstly.

After having purged 10 ml of black and yellow inks from each nozzle group, residual ink of both colors on nozzle plane was wiped away together in longitudinal direction of the printhead by using a rubber blade. This process was repeated up to 10 times and status of color mixture was observed on a solid print image, which was made for three minutes continuously just after the procedure. As far as the inks are in similar surface tension range within 5 mN/m difference, no color mixture is observed even locally.

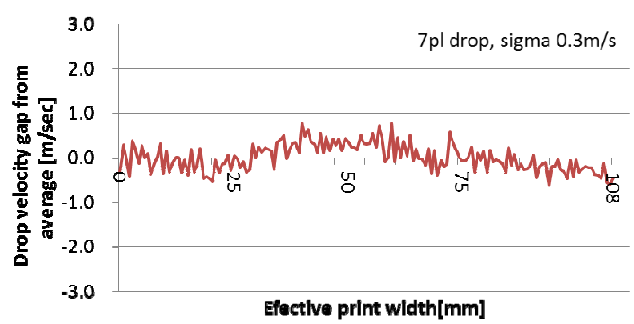
Jetting function

From jetting functional view point, this printhead is designed to eject 5, 7, 12 and 18 pl drops up to 20 kHz and 5, 7 and 12 pl up to 30 kHz with aqueous inks of 5 to 6 mPa*s at operation temperature. It is intended to reproduce same performance as current 600 npi model.

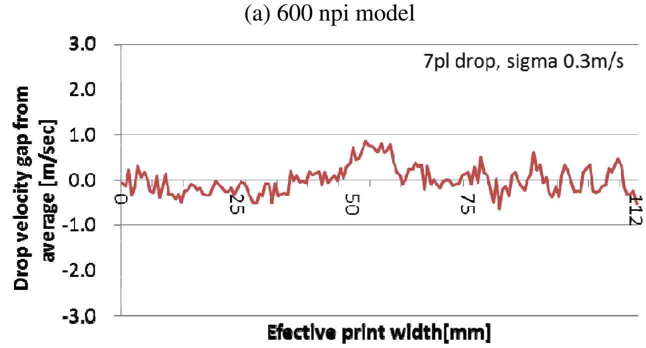
Driving voltage can be adjusted by each trapezoidal unit that covers one inch of print width respectively in order to minimize drop velocity variation across print width in case of 600 npi model.

However, the 300 npi model realizes equivalent drop velocity variation even with fixed single driving voltage across 4.4 inch print width. It is achieved by narrower quality variation in 4.4 times wider actuator unit.

Figure 8 shows examples of drop velocity distribution across print width in one of 16 nozzle rows in cases of 600 and 300 npi models respectively.



(a) 600 npi model

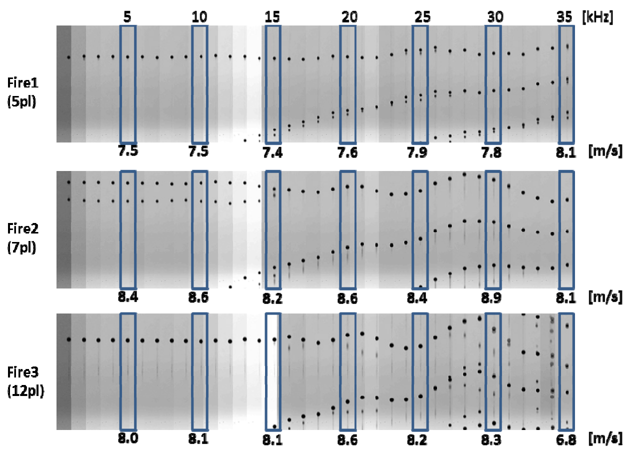


(b) 300 npi model

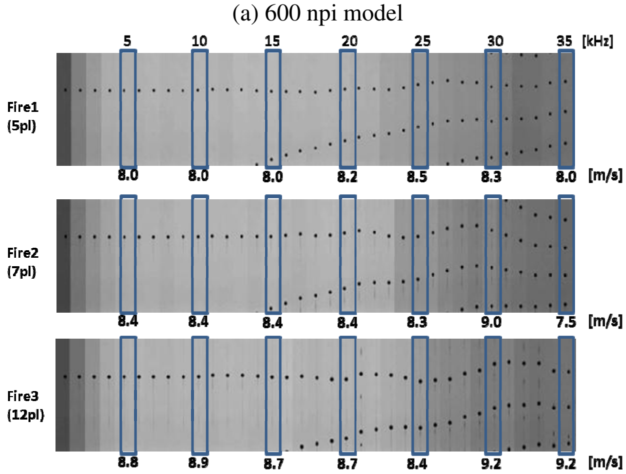
Figure 8 *Drop velocity distributions across print width.*

Figure 9 shows jetting status against drive frequency. Both models show similar tendency in acoustic behaviors although unity and consistency of drops look better with 300 npi model.

It is achieved by modification in drop ejector design to shorten acoustic period by reducing descender length 6.5%. It brings just a little change in primary acoustic period according to the past study but could have had influence to reduce local inertia in descender [4]. As a result, acoustic oscillations locally generated in a descender, which can break drops generated from nozzle, have been weakened in case of 300 npi.



(a) 600 npi model



(b) 300 npi model

***Figure 9** Jetting behaviors vs. frequency*

Crosstalk

As a nature of piezoelectric ink jet printhead, there is mechanical interference between neighboring nozzles, or crosstalk so called. Especially, it can be influential for a high dense ink jet printhead design. In case of KJ4 series, there are crosstalk modes between neighboring drop ejectors in same row and between rows of drop ejectors since they are in matrix arrangement [1].

Comparing to the 600 npi model, nozzle rows are arranged with wider gap in case of 300 npi. Therefore, it is assumed that impact of mechanical crosstalk between actuators can be less with 300 npi model.

In addition, there is influence of pressure propagation between each drop ejector through a manifold. In case of KJ4, drop ejectors aligned in four rows are branched from one manifold. In order to investigate crosstalk effect, from both mechanical and acoustic aspects, drop velocities are measured at several nozzles in driving mode A and B shown in figure 10, in which all ejectors in single row or four rows branched from one manifold across print width are driven together.

Figure 11 shows drop velocity reduction rate of both 300 and 600 npi models by the operation modes A, B at 5 and 30 kHz. Drop velocities of fire 1, 2 and 3, or drop volume of 5, 7 and 12 pl, are averaged in every condition and compared to that obtained by operations at individual drop ejectors.

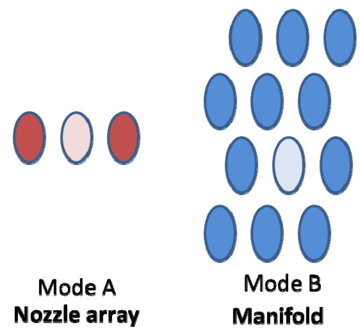
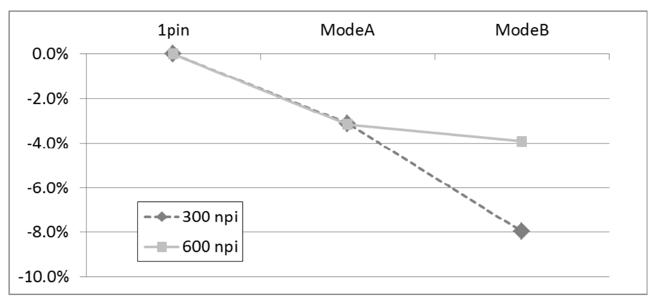
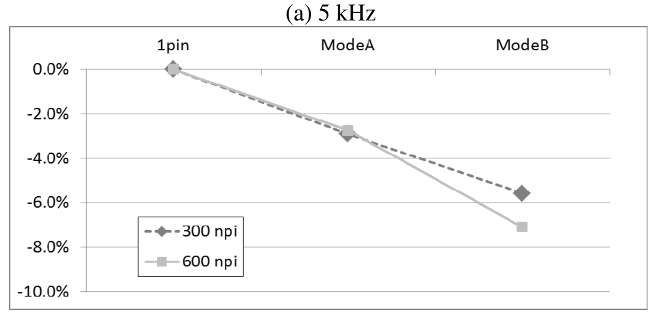


***Figure 10** Driving modes for crosstalk test.*



(a) 5 kHz



(b) 30 kHz

***Figure 11** Drop velocity reduction rate by crosstalk.*

As shown in the figure, drop velocity reduction rate is approximately -3% irrespective of printhead models or driving frequency in case of mode A. It implies that pressure propagation through manifold does not have much impact on crosstalk according to consistency in drop velocity reduction rate. Mechanical interference between neighboring actuators should be primary cause of the drop velocity reduction in this mode.

In case of mode B, there should be influence of mechanical interference between neighboring rows and pressure propagation through manifold. However, drop velocity reduction rate is just 1% lower than that of mode A with 600 npi model whereas it is 4.9% lower with the 300 npi.

Just from mechanical view point, the 300 npi model should be less sensitive since actuator rows are aligned with slightly wider gaps. Taking account of the fact, it should be assumed that acoustic effect in pressure propagation through manifold might have assisted drop generation for 600 npi model driven at 5 kHz.

On the other side, drop velocity reduction rate is lower with 600 npi model at 30 kHz for operation in mode B. It is -7.1, -5.6% for 600 and 300 npi models respectively. It also can be assumed as an effect of acoustic phenomenon caused by pressure propagation through manifold.

From practical view point, it can be concluded that effect of crosstalk should be in equivalent level for both 300 and 600 npi models but internal acoustic behavior is slightly different due to manifold design.

Conclusion

Kyocera developed an ink jet printhead that has 4.4 inch swath, in which two groups of 1328 nozzles are arranged mainly for scanning application. Each nozzle group can be used independently for different inks or colors.

This printhead shares same design concept that has already been established as 600 npi single pass printhead. However, in order to realize printhead structure that involves independent two color channel system, it was necessary to employ monolithic actuator unit that covers the whole print width, which was covered with four actuator units in case of the original printhead model.

Jetting performance, or capability for drop generation, is almost identical as the original model including characteristic dependency on drive frequency and drop velocity variation in a printhead.

There is difference in tendency of crosstalk against drive frequency from the original model although the magnitude of influence is more or less similar range.

This printhead has already been introduced into the market and working in a scanning printer. The performance and reliability has been proven.

References

[1] A. Hirota, S. Ishikura, "Development of Drop - on - Demand Piezoelectric Line Ink jet Printhead", Proc. NIP21, IS&T, p257 - 263 (2005).

[2] S. Ishikura, A. Matsumoto at el, " Improvement of piezoelectric ink jet printhead for higher throughput", Proc. NIP25, IS&T, p257 - 263 (2009).

[3] S. Ishikura, M. Hibi, "Acoustic Analyses on Oscillatory Behaviors in Piezoelectric Ink Jet Printhead", Proc. NIP22, IS&T, p75 - 78 (2006).

Author Biography

Kazuya Yoshimura was given his B.Eng. degree in electronics engineering from Ritsumeikan University in 2008. He joined Kyocera Corporation in the same year and started his career as a print head designer. Since then, he has been playing key role in the development.

Naoki Kobayashi graduated Kurume College of Technology in 2007. Then, he joined Kyocera Corporation and have been working for development of piezoelectric actuator.

Chisako Mizumoto received her B.Eng and M.Eng degree in mechanical engineering from Kobe University in 2010 and 2012 respectively. Then, she joined Kyocera Corporation and have been working for printhead development.

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.