Newly Developed MEMS Print Heads for Industrial Inkjet Applications

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Abstract

We have developed new print heads suitable for industrial inkjet applications by combining long experience in industrial inkjet business and novel MEMS technology.

Print heads used in industrial inkjet applications are required high precision, high durability and compatibility to a wide range of ink.

To meet these requirements, we chose bulk PZT material for an actuator, and Si MEMS technology for processing of ink channels and nozzles. The bulk PZT material has high durability against thermal and mechanical stresses and enables to use an internal heater to raise ink temperature up to 60 degrees Celsius. Si based ink channels and nozzles have high mechanical precision and can achieve high jetting straightness and high uniformity of droplet velocity and droplet size.

We have also developed new ink channel dimensions and driving waveforms to achieve small binary droplet size of 3.5 pL and high pump ability of 20 pL at 24 kHz.

Our new print heads have already tested in a wide range of applications from sign and display to printed electronics markets.

Introduction

Inkjet printing has been expanding into many kinds of applications. Consumer inkjet printers and wide format inkjet printers for signage are already used all over the world. In addition to these applications, inkjet technology is also utilized in digital production printing like inkjet press [1] and inkjet textile printers recently because of the advantage of no plates required and capability of printing flexibility like printing variable data and/or printing small number of sheets per job.

Print heads used in such industrial applications are required not only high image quality and high precision, but also high durability and compatibility to a wide range of ink. The next generation print heads for the application should meet these demands.

Konica Minolta, Inc. has been developing and providing inkjet print heads to industrial inkjet market for more than 10 years. [2] Our print heads have compatibility to a wide range of ink from high viscosity UV curable ink to water based ink, by equipping an internal heater and ink flow channels which have high resistance against water solution. We also have developed novel bend mode print heads with small droplet size of 1 pL and high jetting accuracy for printed electronics applications by applying MEMS (Micro Electro Mechanical Systems) technology. [3]

Now we have developed new MEMS print heads suitable for industrial inkjet application by combining long experience in industrial inkjet business and novel MEMS technology.

Our new print head, M600SH-2C, consists of Silicon (Si) based ink channels manufactured by MEMS technology and PZT (lead zirconate titanate) actuators made from bulk PZT ceramics.

Print Head Specifications

Table 1 shows specifications of M600SH-2C. As shown in the table, M600SH-2C equips an internal heater.

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In general, bulk PZT actuator has high durability against thermal and mechanical stresses compared to thin film actuator [4]. Therefore, it enables to equip a head internal heater to raise ink temperature up to 60 degrees Celsius. The internal heater allows to use a wide range of UV curable ink. Si based ink channels and nozzles have high mechanical precision and can achieve high jetting straightness and high uniformity of droplet size.

The print head can jet multiple drop volumes. The minimum drop volume is 3.5 pL and the maximum is 20 pL. Fig. 1 shows 3.5 pL, 10 pL and 20 pL dots printed by M600SH-2C. Each dot shows almost perfectly roundness and repeatability. This was achieved by fine nozzle structure manufactured by Si MEMS technology.

Table 1 Specifications of M600SH-2C.

Print head name	M600SH-2C
Jetting method	On-demand piezoelectric
Number of nozzles	1024
Nozzle resolution [npi]	600 (300 x 2)
Jetting frequency [kHz]	42 (3.5pL – 10pL multi) 24 (20pL multi)
Drop volume at 6m/s [pL]	3.5 – 20
Maximum gray scale	7 levels *depends on ink characteristics
Ink viscosity [mPa·s]	7 – 10
Driving voltage (maximum) [V]	25 – 30 (36)
Print width [mm]	43.3
Multi-color	1/2 color compatible
Applicable ink	Solvent, Oil, UV, Water base
Ink temperature [°C]	RT to 60
Internal heater	Available

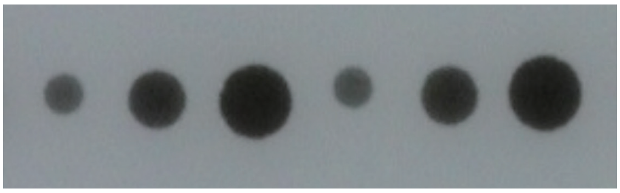

Fig. 1 Repeatable dots of 3.5pL, 10pL and 20pL.

Structure of Print Head

Fig. 2 shows the outline image of M600SH-2C. Total 1024 nozzles are placed in 64 × 16 matrix.

The print head consists of Si MEMS based chips and two independent ink flow passes from an ink inlet port to nozzles. This structure enabled to use the printhead as 600 npi single color or 300 npi double color compatibly in a compact chassis. The compact 300 npi double color print head is ideal for small scanning printers. The distance of each color's nozzle row was designed to prevent color mixture after purging ink as shown in Fig. 3.

Fig. 2 Outline of M600SH-2C.

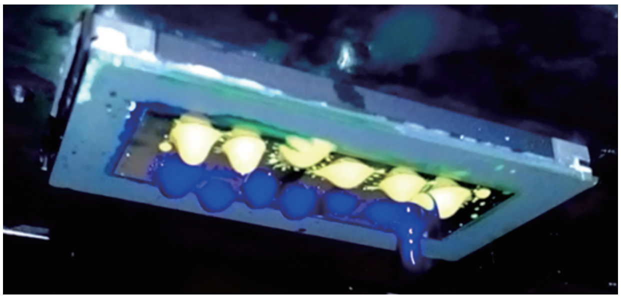

Fig. 3 Nozzle plate surface after purging.

Fig. 4 shows schematic image of the individual channel. Individual ink flow channels were formed by stacking several Silicon MEMS based chips. Ink flows into the individual channel from reservoir locating upper side of the MEMS based chips and is ejected from the nozzle by PZT actuator.

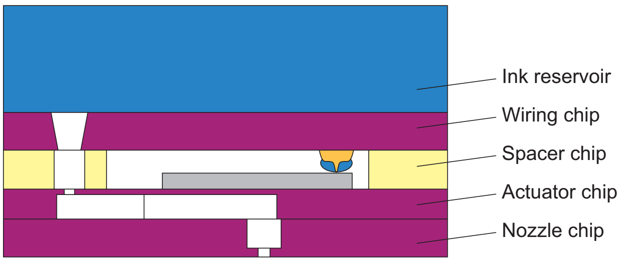

Fig. 4 Schematic image of individual channel.

Channel Design Study

M600SH-2C has both small binary droplet size of 3.5 pL and high pumping ability of 0.42 μL/sec per nozzle by jetting 20 pL at 24 kHz. These features were achieved by newly designed actuators and ink flow channels.

Simulation Study of Negative Pressure

To achieve the target specifications, negative pressure control is important. Negative pressure is generated in the pressure chamber after ink droplet is ejected by the movement of the actuator. In general, the channel dimension for native small droplet has large negative pressure, however, such large negative pressure causes unstable jetting in multiple dot jetting at high frequency by generating micro air bubbles in the channel.

We estimated the negative pressure level by simulation method combining a finite element method and an equivalent circuit model. Fig. 5 shows an actuator model of the finite element simulation and Fig. 6 shows calculated pressure wave generated in the pressure chamber by a jetting pulse. As shown in this graph, the pressure wave was damped oscillation with natural frequency and negative pressure became maximum just after droplet was ejected.

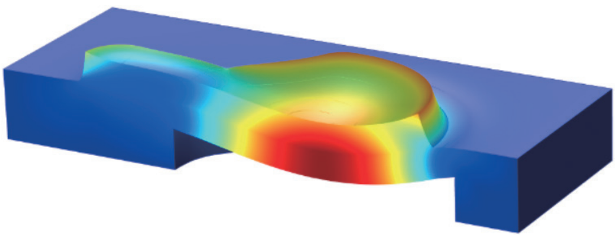

Fig. 5 Simulation model of an actuator.

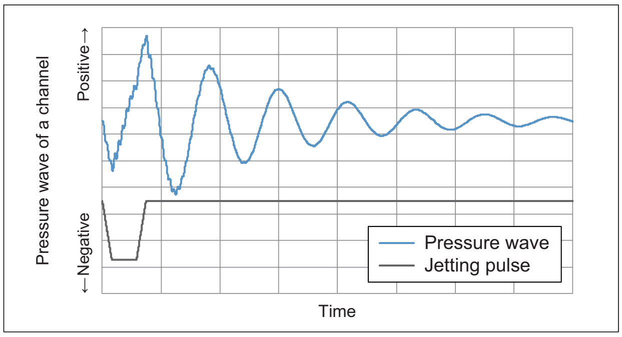

Fig. 6 Simulated pressure wave.

Experimental Results of Negative Pressure

To determine the upper limit of maximum negative pressure level for stable jetting, relationship of simulated negative pressure level and jetting failure rate of actual print head nozzles was confirmed by preparing several test pieces designed with different negative pressure level and jetting stability test was conducted with the test pieces. For this experiment, the number of driving nozzle was reduced to eliminate the influence of cross talk or ink refill. Negative pressure level was controlled not only by the channel dimension, but also by adjustment of the driving voltage.

Fig. 7 shows the results of the experiment. From those results, our design target of maximum negative pressure was determined to eliminate any nozzle failure even in high duty jetting state.

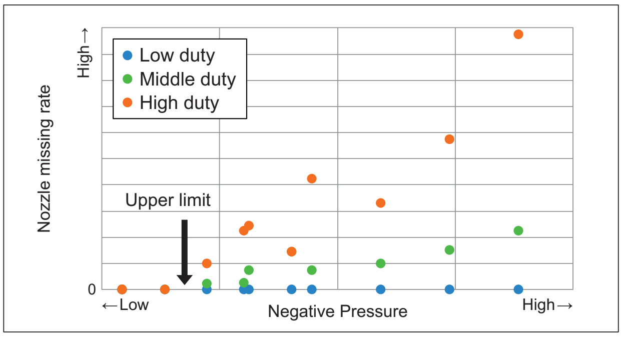

Fig. 7 Relationship between nozzle missing rate vs negative pressure.

Optimized Design for Multiple Dot Jetting

From the simulation and experimental data, the ink flow channel and the actuator dimensions were optimized. This new design could achieve multiple-dot jetting of 20 pL which has six times of native droplet size of 3.5 pL, at high jetting frequency of 24 kHz.

Fig. 8 shows the comparison of calculated maximum negative pressure of Konica Minolta's existing print heads line-ups and newly developed M600SH-2C. The new print head showed almost a half of the existing print head which had the same native droplet volume.

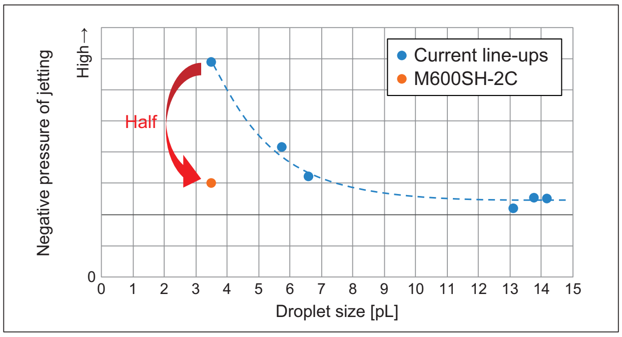

Fig. 8 Relationship between droplet size vs negative pressure.

Jetting properties and applications

Fig. 9 shows droplet velocity dependence on jetting frequency of variable dots of 3.5 pL, 10 pL and 20 pL with actual UV curable ink from markets. As shown in the graph, droplet velocity fluctuation caused by remnant pressure wave vibration was small in each droplet size jetting mode due to optimized channel design.

Fig. 10 shows jetting angle deviation of M600SH-2C. The angle deviation was measured with a drop watcher at 10 kHz. The result showed that small 3.5 pL droplets were ejected with the angle deviation of 0.5 degree or less. This was achieved by fine nozzle shape manufactured from Si by MEMS process.

This precise jetting property enabled to apply the print head for industrial printing like printed electronics.

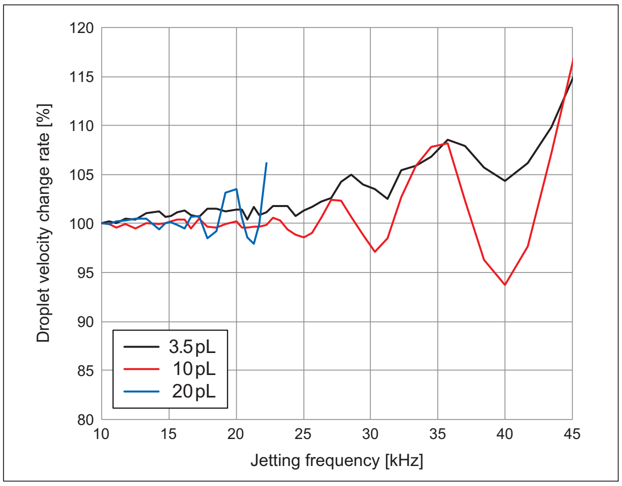

Fig. 9 Droplet velocity dependence on jetting frequency.

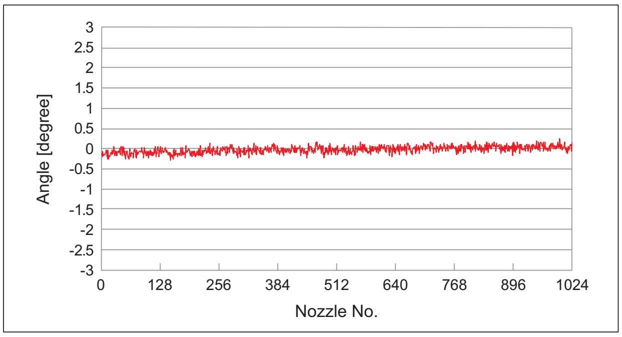

Fig. 10 Jetting angle deviation of M600SH-2C.

Conclusion

New print heads suitable for industrial inkjet applications were developed by utilizing reliable PZT actuators and novel Si based ink flow channels manufactured by fine MEMS processing technology. Newly designed ink channel dimension was optimized for multiple-dot jetting with variable dot size from 3.5 pL to 20 pL.

Variable fine dot shapes and small jetting angle deviation were achieved by precise nozzle structures made by Si MEMS technology.

Our new print head, M600SH-2C, can be applied not only sign and display markets but also printed electronics markets.

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Author Biography

Kenji Mawatari received his B. S. and M. S. degree in physics from Tohoku University. He joined KONICA MINOLTA, Inc. in 2008. Since then he has been engaged in the development of ink jet printheads. He has focused on research and development of MEMS inkjet printheads for 10 years. He is also in charge of supporting customers technically.

Acknowledgment

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