Air Bubble Management on a New Thermal Ink Jet Head

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Abstract

In Thermal Ink Jet printers, air bubbles generated in the ink fluid path have been identified as a cause of clogging the nozzles for ink supply, resulting in image defects. As a corrective method, a suction maintenance has been used to periodically discharge air bubbles from the nozzles with ink.

However, the suction maintenance has had a problem of increasing the cost of the device and the volume of waste ink.

To solve this problem, we have improved the structure of a manifold for ink supply to a head reservoir. This new manifold design enables air bubbles generated in the head reservoir to move to the upper part of the manifold by buoyancy, and also causes no pressure fluctuations at ink jetting.

In addition, we have found a new reliable maintenance method named a “Super Heat Dummy Jet (SHDJ).” This method uses a boil phenomenon of ink in the head reservoir.

With a smaller energy of drive pulses than that in normal printing, the SHDJ can raise the temperature of head until ink in the head reservoir boils. The boiling of ink makes air bubbles expand and move to the upper part of the manifold.

As the result, we have realized a stable and simple air bubble management technology.

Introduction

For high-speed printers, keeping good print quality is highly demanded. Especially, a print defect due to air bubbles generated during printing is one of the major problems in terms of print quality.

In this paper, we present an air bubble management technology, which is implemented in the newly developed print head cartridge (Figure 1). It is called as an “Advanced and Simple Ink Path Head Cartridge (ASIP Head Cartridge).”

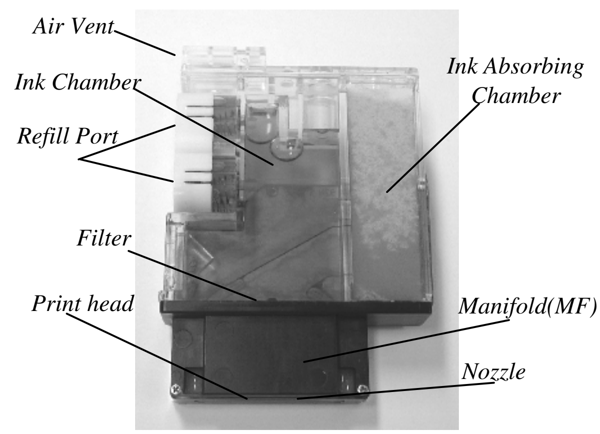
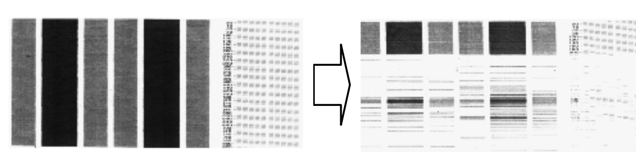


Figure 1. Print head cartridge (Special transparent model)

Air Bubbles Study

Generally, the temperature of print head goes up during printing in thermal inkjet. The increase in head temperature raises the temperature of ink in the ink flow path, and as the result, air bubbles are deposited due to the air solubility reduction. Air bubbles deposited in the head will grow and clog the nozzles, then causes jetting inability, as the result some print defects occur.

Figure 2 shows a print defect sample taken after 300 prints of 5% coverage A4 size paper.



Initial sample *After 300 prints sample*

Figure 2. Print defects by air bubbles

Figure 3 shows the curve of air solubility in water. Water-based ink follows the similar change of solubility.

ΔV in the figure represents the amount of air generated by the increase of temperature. (20°C•55°C)

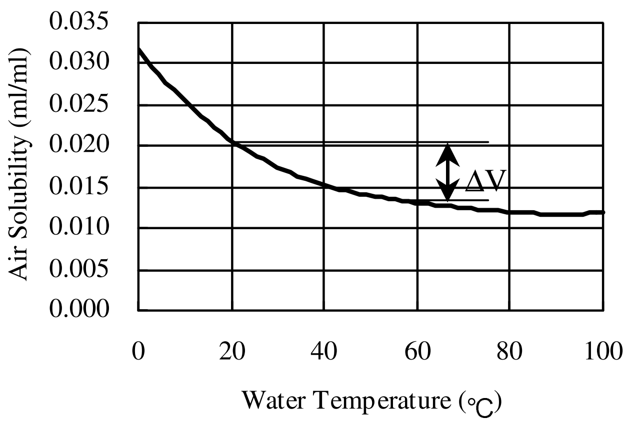


Figure 3. Air solubility curve in water

Regarding the location of deposited air, sites are categorized into three groups:

1) being jetted out of the print head together with ink
2) being accumulated in the print head and manifold
3) being accumulated in the ink chamber

Air bubbles causing print defects are the ones that stay in the print head and grow up to the size at which the nozzle fluid path is clogged.

Improved Manifold

Structure

Figure 4 shows the photo of the print head with a side shooter structure.

The print head is fabricated by laminating two Si wafers. The upper is a channel wafer that forms a nozzle fluid path, and the lower is a heater wafer that forms a heater circuit. The nozzle fluid path is configured by processing Si by means of Orientation Dependent Etching (ODE) and Reactive Ion Etching (RIE).[1]

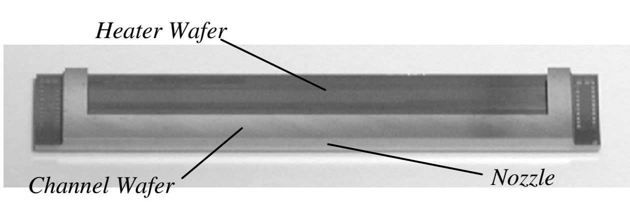


Figure 4. Print head

The conventional manifolds had a thin pipe-shaped structure (diameter: 1mm, height: 17mm). With this structure, air bubbles being generated in the reservoir of the head cannot move to the manifold, and they stay and grow in the head reservoir, by which the nozzles are clogged, resulting in print defects.

We have found a new method for managing air bubbles using a higher volume manifold, in which air bubbles in the head reservoir are actively moved up and accumulated into the manifold.

Figure 5 shows the structure of an improved manifold. The manifold is fabricated by a double injection mold having an elastomer, and the elastomer seals the print head. With this structure, ink can flow straightly from the manifold to the print head. Generated air bubbles can float straightly from the head reservoir to the manifold.

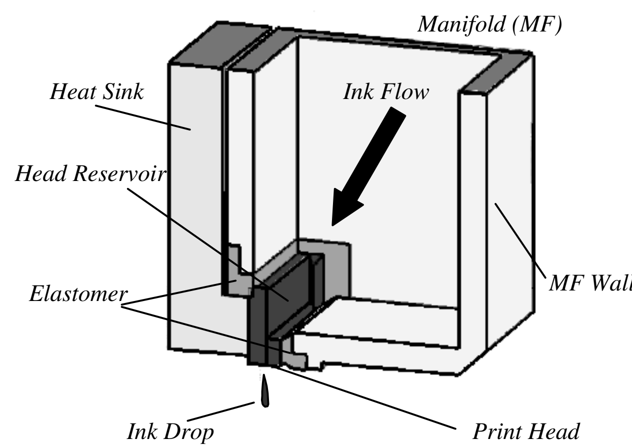


Figure 5. Improved Manifold structure (cross section diagram)

Simulation

The motion of air bubbles is governed by two forces. One is buoyancy and the other is ink flow drag force.

The buoyancy 'F1' and the drag force 'F2' can be described by the following formulae:

$$F1=\rho g\pi d^3/6 \qquad (1)$$

where ρ, *g* and *d* are ink density, gravity constant and bubble diameter respectively.

$$F2=Cd\rho v2\pi d^2/8 \qquad (2)$$

$$Cd=24/Re \qquad (3)$$

$$Re=\rho vd/\mu \qquad (4)$$

where Cd, v, Re and μ are resistance coefficient, ink velocity, Reynolds number and ink viscosity respectively.

For the case of no print (F2=0), air bubbles move to the upper part of the manifold by buoyancy unless they are attached to the wall.

During printing, whether an air bubble goes up to the manifold or goes down to the print head is determined by the balance of F1 and F2.

Conventionally, when air bubbles with a larger size exceeding several hundreds microns moved from the manifold to the reservoir, they clogged the nozzle fluid path, and subsequently print defects occurred.

Figure 6 shows the simulation of ink flow velocity in the conventional and improved manifolds. You can see that the ink flow velocity in the improved manifold gets very slower.

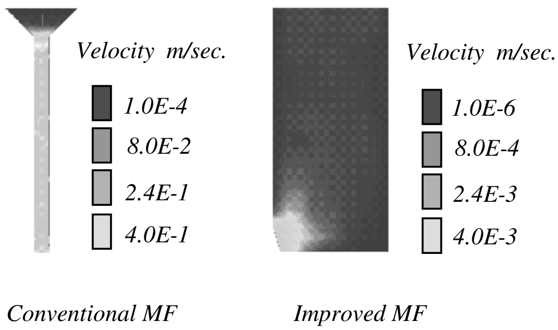


Figure 6. Ink flow velocity simulation

Figure 7 shows the relationship between the ink flow velocity and the diameter of air bubbles moving to the head. From this, it could be concluded that the improved manifold shows approximately 1/100 ink flow velocity during printing, and the air bubbles moving to the head reservoir have a very small size of 100 um or less.

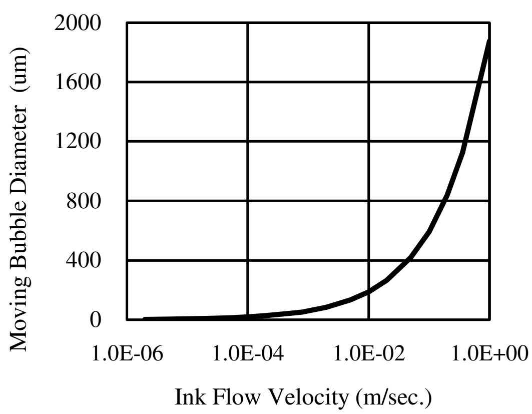


Figure 7. Moving bubble size vs. Ink flow velocity

Experimental Air Bubble Failure Life

Table.1 Air Bubble Failure Life

	Conventional manifold	Improved manifold
Average failure life volume	349 pages	>5000 pages
σn-1	72 pages	-
Manifold inside size	Diameter: 1mm-5mm Height:17mm	Width:27mm Depth:8mm Height:17mm

Table 1 shows a comparison of the print volume until air bubbles-induced defects occur between the conventional and improved manifolds.

From the above, we conclude that air bubbles-induced defects can be prevented completely by adopting the improved manifold.

Pressure Fluctuation

Another big issue for designing manifolds has been a pressure fluctuation in manifold during ink jetting. Jetting frequency closer to the specific frequency of ink supply system in the print head cartridge makes the meniscus in the nozzle surface unstable, causing no jetting.

When the ink supply system is treated as a pressure-electricity equivalent circuit, and the pressure pulse by ink jetting is represented as E(t), the equation of fluid pressure fluctuation[2] is described as:

$$(L1+L2)\frac{d^2P}{dt^2}+(R1+R2)\frac{d^2P}{dt}+\frac{1}{C1+C2}P=E(t) \qquad (5)$$

where P is the pressure in the head reservoir, L1 and L2 are an inertance of the nozzle fluid path, an inertance of the manifold, R1 and R2 are a resistance of the nozzle fluid path, a resistance of the manifold, C1 and C2 are a capacitance by the meniscus in the nozzle surface, a capacitance of the manifold, respectively.

The attenuation ratio is:

$$\zeta=\frac{(R1+R2)}{2}\sqrt{\frac{(C1+C2)}{(L1+L2)}} \qquad (6)$$

The maximum amplitude amplification factor of the pressure 'M' is:

$$M=\frac{1}{2\zeta\sqrt{1-\zeta^2}} \qquad (7)$$

To prevent pressure fluctuation, M must be smaller or equal to 1, then

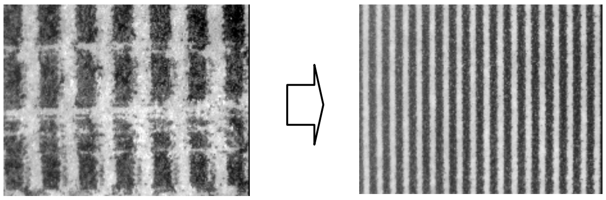
$$\zeta>\frac{1}{\sqrt{2}}\approx 0.707 \qquad (8)$$

Table 2 shows the M and resonant frequency.

Table.2 Maximum amplitude amplification factor M

	M	Resonant frequency
Conventional manifold	3.18 times	2282 Hz
Improved manifold	<1 times	4284 Hz

Figure 8 shows the results of print test for repeated jetting around the actual resonant frequencies. The test showed that as assumed, the improved manifold doesn't have any problems, such as no jetting, due to pressure fluctuation.



Conventional manifold *Improved manifold*

Figure 8. Print defects by pressure fluctuation

Air Accumulation

To estimate the balance of accumulated air, we have observed the actually accumulated air volume using an X-ray transmission apparatus.

Table 3 shows the rate of air accumulation per consumed (jetted) ink volume.

Table 3. Air Accumulation Rate

	Inside manifold	Inside ink chamber	Ejected outside (Estimated)
Accumulation rate	0.54 mm^3/ml	1.6 mm^3/ml	(5.4) mm^3/ml
Accumulation ratio	7%	21%	(72%)

The print head was operated at a saturated temperature of 55C°. Total air volume is estimated to be 7.5mm^3/ml from Figure 3. Therefore, 5.4mm^3/ml (72%) was thought to be carried out by the ejected ink.

The quarter of the 28% is accumulated in the manifold that is located in the lower part of the filter, and the remainder (3/4) is accumulated in the ink chamber that is located in the upper part of the filter. The air accumulated in the ink chamber is exhausted outside by the refill unit of the printer and is replaced with new ink.

Hence, it becomes obvious that the life of head cartridge is dependent on the volume of air bubbles that are accumulated in the manifold.

Super Heat Dummy Jet

As described in the above, we have realized a robust and highly reliable head cartridge in terms of air bubbles and pressure fluctuation through the ASIP design.

However, when some mechanical impact is given to the head during the initial installing of head cartridges, air sometimes happens to be sucked into the head reservoir from the nozzles.

Conventionally, air bubbles that have been sucked from the nozzles and adhered onto the nozzle fluid path have been removed by a suction maintenance system because the bubbles cannot be removed by normal jetting.

Now, we have developed a new method called a "Super Heat Dummy Jet (SHDJ)" to remove air bubbles by boiling ink in the head reservoir.

The print head structure of Si+Si enables the head to be heated up to the boiling point of ink because the heat resistance is high.

Figure 9 shows the sequence of SHDJ. That is, since the boiling point of water-based ink is around 100°C, the head is heated up to 100°C to boil ink in the reservoir where air bubbles are expanded and moved to the upper part of the manifold. In the SHDJ method, voltage with a small pulse width that makes no ink jet is applied. Accordingly, it becomes possible to perform a maintenance job without generating large amount of waste ink.

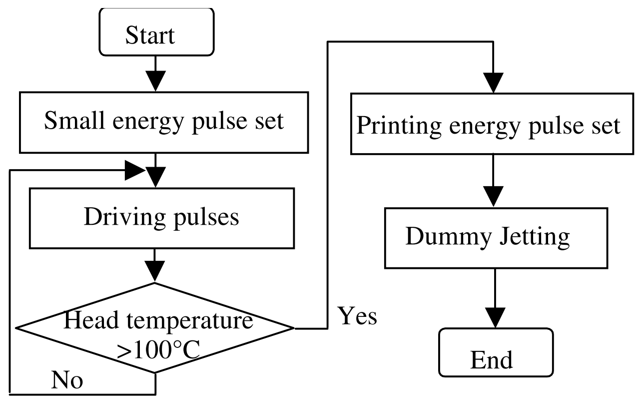
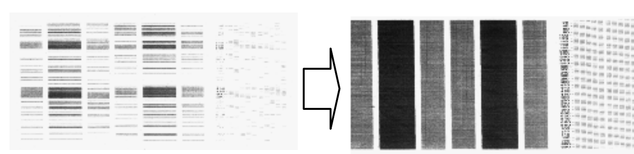


Figure 9. SHDJ sequence



Before *After*

Figure 10. Recovery of print defects by SHDJ

Its capability is shown in Figure 10.

Figure 11 shows the state of air bubbles in the head reservoir observed by the X-ray transmission apparatus. The adhered air bubbles can be completely removed by the SHDJ.

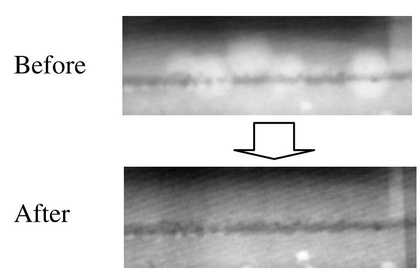


Figure 11. Air bubbles eliminated by SHDJ

Conclusion

We have realized a highly stable air bubble management technology. Also, the use of the air bubble management system can simplify the maintenance method in ink jet printers.

References

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Biography

Kazuyuki Oda was born in Japan in 1967. He received B.E. degree in Precision Engineering from Osaka University in 1990. In 1990, he joined Fuji Xerox Co., Ltd. Since then, he has been engaged in research and development of thermal ink jet. He has specialized in ink fluid system design of printing head and ink tank. He holds 10 US patents and 30 JP patents of ink jet technologies. He has been a member of IS&T since 1996.