Using Perturbed and Asymmetric Microflow Architectures to Statistically Clarify Droplet-Ejected Deflection in Picoliter and High-Frequency Inkjet

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Abstract

Currently a lot of experienced efforts for inkjet printing were paid to promote the print quality with high-density nozzles (>/= 600 nozzles per inch, npi) and little droplet (<10 picoliter, pL) since the inkjet can approach the photographic printing. In addition of promoting resolution, an accurate directionality of droplets ejected and flying vertically from nozzles is also essential to get a faultless print quality. This work at first developed a new method of statistically evaluating the droplet deflection by the dot-images printed on media. Different microflow architectures (*arches*) for thermal-bubble inkjet (TIJ) heads with perturbed orifices were designed in order to eject the droplets of 5~7 pL with the jetting frequency of 5~19 kHz. A variety of drop velocities were individually got by these different nozzle geometry to adjust the influence of deflection due to the asymmetry and the perturbation of orifices. Meanwhile the factors injuring or degrading the vertical directionality can be clarified. These evaluations of new microflow arches indicate the factors to reduce deflection and therefore approach the high-quality printing.

Introduction

An ideal print quality for inkjet printing is attributed to the accuracy of drop projection. It's expected that all drops should be ejected-out vertically from the nozzles. However, many external factors such as perturbation, ink clog, ink puddling around the orifices inevitably deflect the drop-ejected direction. These deflection factors usually result from the orifice circularity, easy dry or cloggy ink-property, and the correlation property between ink and nozzle surface. In addition, a high enough drop-velocity can reduce the effect of external deflection factors and serve an important role to promote the accuracy of drop-projection. For a TIJ head, it's difficult to change the drop velocity at liberty by controlling the energy applied to the actuators.[1] The drop velocity of a TIJ head is only dominated by internal factors such as the microflow architecture,[2] the orifice geometry[3] and the ink viscosity. Several contributive conclusions were proposed by Chiu et al with simulative calculation, including the relationship between the heat flux and bubble pressure,[4] between drop velocity and drop viscosity,[5] and the better design of ink-feed-channel.[5] A continuous drop-ejecting and vision system has been already constructed and used[4,5] for inspecting the inkjet performance at various applied energy and frequency.

This work is mainly concentrated on the characteristics of drop velocity and drop-ejected deflection. We at first designed and created a new apparatus to inspect and calculate the deflection. By comparing the position of nozzles and actual dots, we got the deviation of a group of nozzles in a head. Subsequently, we prepare some TIJ printheads to generate various drop-velocity and cause asymmetry perturbation due to different design of nozzles. By these samples, the deflection affected by orifice perturbation can be investigated.

Experimental

A. Apparatus for Dot-Printed Accuracy Inspection

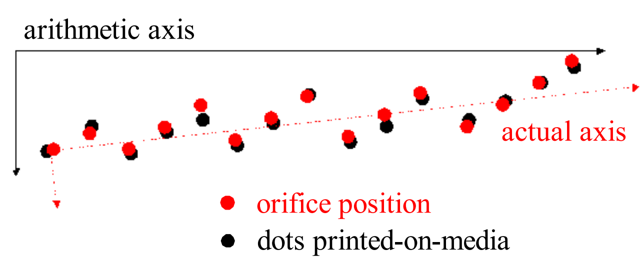

Figure 1. Illustration of deflection arithmetic for drop-ejection accuracy.

Figure 1 shows the main concept used for the deflection clarification of drop-ejection in this work. A continuous drop-ejecting system has been already constructed.[4,5] The printed media and the printhead are fixed, and only a drop is ejected out by each nozzle. An ideal drop-ejection should make all dots-printed locate consistently with the corresponding nozzles. Substantially, the printed dots are inevitably deflected and deviated from the corresponding nozzles, as illustrated in Fig. 1. By the sum or average of all dots' deviation, the magnitude of deflection can be statistically quantified. To get this deviation, we designed and constructed a dot-printed accuracy inspection (DPAI) system, shown in Fig. 2 and providing the functions of (1) printing single dot for each nozzle, (2) inspecting multiple dot-images, and (3) calculating the deviation by the dot image. The DPAI system drives a printhead to eject one drop per nozzle. Figure 3 shows the dots' image got by the DPAI system driving a 600 dpi printhead. So far, the driving firmware isn't optimized, the dot lost is often observed if driving >36 nozzles in one head to eject only a drop per nozzle at one time. Therefore the lost dots are temporarily unconsidered to the statistical deviation herein.

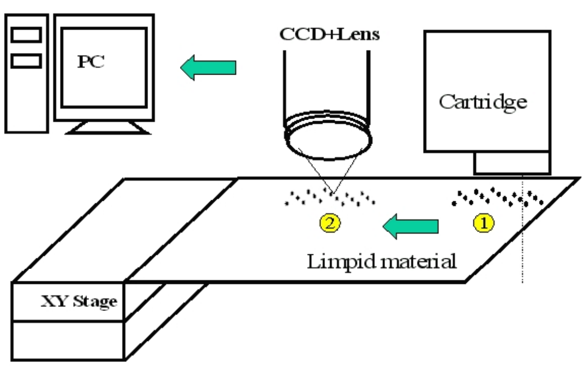

Figure 2. Schematic apparatus of dot-printed accuracy inspection (DPAI) system (patent pending).

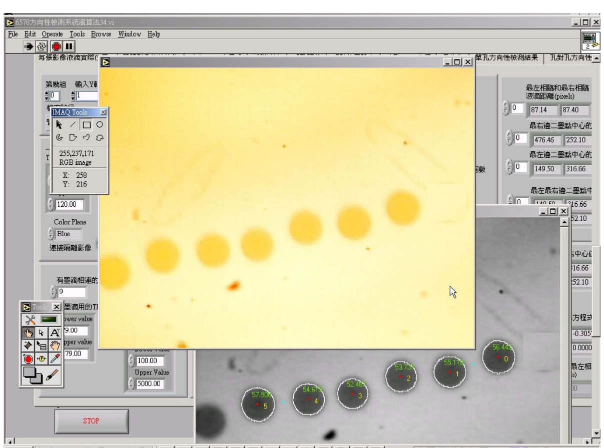

Figure 3. Image comparison of dots printed-out by DPAI system.

Printhead Preparation

Several printheads with asymmetry microflow arches were prepared for creating various drop velocity and inkjet perturbation. The ink-feed channel in microflow arch of TIJ head is mainly classified to symmetry or asymmetry category dependent of the inlet of heater. The single inlet is symmetry ink-feed, as shown in Fig. 4(a); on the other hand, the firing chamber with double inlets is probably symmetry if the design can make ink enter the firing chamber symmetrically, as similar to Fig. 4(b). Due to the incomplete experiments, we are not sure the ink-feed channels shown in Fig. 4(b) can provide ink flow symmetrically. Only asymmetry ink-feed channel was used for this study.

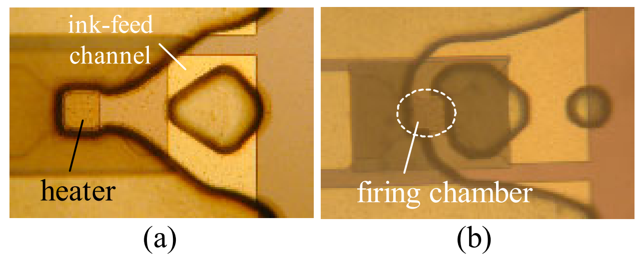

Figure 4. (a) asymmetry, (b) symmetry ink-feed architectures of printheads designed for inkjet of 5~7 pL and 15~19 kHz.

After heater and ink-feed channel fabrication, a variety of nozzle plates with different orifice diameter and thickness were fabricated by nickel electroforming and gold surface-coating. On purpose of 5~7 pL drops, the heater size is 23x23 um^2 and the diameter of orifices (D_{orf}) is 13~14 um. Different thicknesses of nozzle plates (TK_{NZ}) are fabricated with 21, 26 and 31 um in order to define different drop-velocity, as list in table 1. In addition, as shown in Fig. 5, the perturbation is generated by asymmetry orifices with the protruding (B2) or recess (B4). The ink used herein is with the 1.6 cps viscosity and the about 32 dyne/cm surface tension. Employing these 5 nozzle-geometry, the characteristics of deflection affected by drop velocity and perturbation can be investigated.

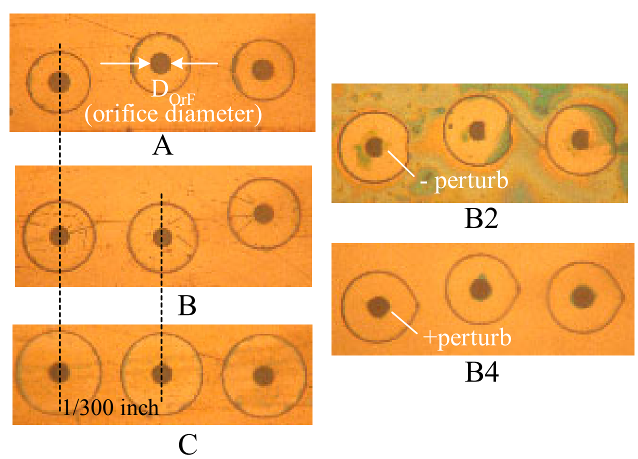

Figure 5. Photographic surface-view of different NZ-geometry types (list in Table 1)

Table 1. Key parameters of different nozzle (NZ) geometries.

NZ	Diameter	Thickness of NZ-Plate	Perturb
A	14.3 (um)	21 (um)	0
B	14.2	26	0
B2	14.2	26	~ -2um
B4	14.2	26	~ +3um
C	13.2	31.5	0

Results and Discussion

Dot Accuracy Affected by Drop-Velocity

As above description, it's likely the simplest method to change drop velocity by modifying the orifice-plate thickness. By the continuous drop-eject and vision system, we got experimentally 3 different drop-velocity (Vdrop) in NZ geometry A, B and C. As shown in Fig.6, the NZ-A with lowest Dorf/TKNZ ratio contributes to the highest Vdrop at all delay time. and the NZ-C with the thickest nozzle-plate causes the lowest Vdrop. The Vdrop of 5 NZ-geometry are calculated in detail and list in table 2. This trend is consistent with the proposed results.[3] The Vdrop of B4 is higher than that of B2 should be due to the positive perturb enlarges the orifice area at the same NZ-plate thickness.

Figure 7 shows the drops jetted at 15 and 19 kHz in NZ-A and NZ-C. Compared to Fig.6, there is no significant difference of droplet between 5 kHz and 15 & 19 kHz in NZ-A and NZ-C. Except for the perturbed NZ, all NZ-geometry prepared for 5~7 pL have the ability of jetting with high frequency.

To inspect and evaluate the deflection of dots printed-out, a photography image of single-dot per nozzle was first printed by DPAI, as shown in Fig.8 on the last page of this paper. Sequential 36 nozzles were used for DPAI analysis at one time. The inspection method of evaluating more nozzles (>36) is still developed and established. An average deviation (DV_{ave}) is defined as following:

$$DV_{ave} \equiv \frac{\sum_i \sqrt{(X_{i,dot} - X_{i,NZ})^2}}{N}$$

where ($X_{i,dot}$-$X_{i,NZ}$) is the distance between actual dot and the corresponding nozzle, N is the number of dots actually printed-out ($N \leq 36$). The lost dots were ignored. The DV_{ave} indicates the average dot-deviated distance per nozzle. If DV_{ave} approaches to be 0, it is an ideal directionality accuracy. NZ-A shows a lowest DV_{ave}. A significant trend is that the higher V_{drop}, the lower DV_{ave} is. This result reveals an important factor that a high drop-velocity can be contributed to an accurate drop-ejected directionality.

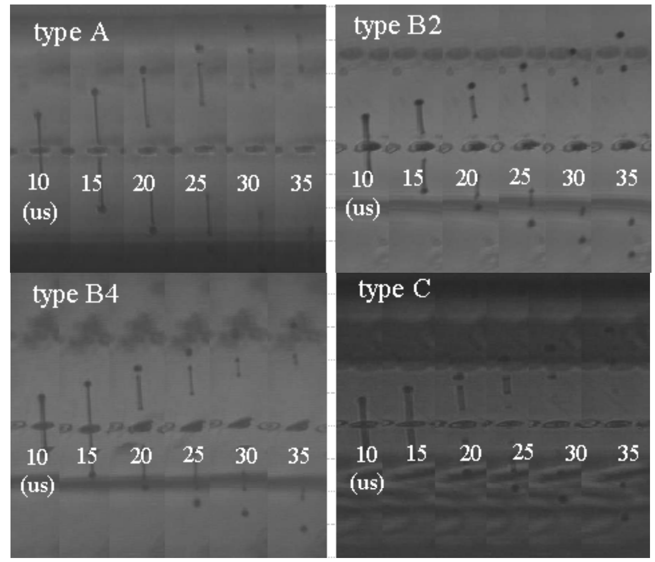

Figure 6. The drop-ejected vision of various orifice types jetted by 12V, pulse witdh 1.6 us (~1.6μ-joule/per drop), 5 kHz and delay 10~35us.

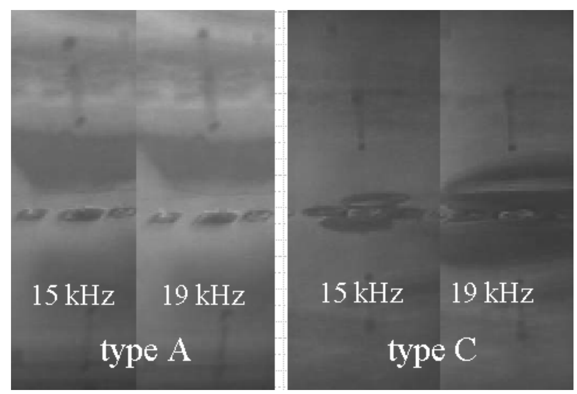

Figure 7. The droplet vision of type A and C jetted by 15 kHz and 19 kHz (delay 30 us), respectively.

Table 2. The drop velocity and the average deviation of dots printed-out and inspected with DPAI system.

NZ	D_{orf}/TK_{NZ} (um)	V_{drop} (M/s)	DV_{ave} (um)
A	14.3/21	20.6	11.97
B		15.6	24.01
B2	14.2/26	14.1	103.67
B4		17.1	N.A.
C	13.2/31.5	12~14 (unstable)	86.89

Dot Accuracy Affected by Nozzle Perturbation

Figure 9 shows the dots distribution of perturbed NZ-B2 with 36 sequential nozzles drived by DPAI system. An scattering and deviation from each nozzle position is more obvious. The DV_{ave} of NZ-B2 is further higher than that of NZ-C and much worse than the NZ-B with identical D_{orf} and TK_{NZ} but asymmetry orifices. In spite of the same perturbation used for all nozzles in NZ-B2, the protruding perturb of orifices frustrates the drop-ejection and make more deviation. So, the orifice perturb is the other important factor to injure the inkjet accuracy.

The NZ-B4 cannot be successfully printed-out and evaluated for DV_{ave} by DPAI system due to too many dots-lost.

Conclusion

The drop velocity and the orifice integrity play an important role of affecting dot-ejected accuracy. In this work, we established a dot-printed accuracy inspection system to statistically evaluate the deviation of 36 sequent nozzles. An index DV_{ave} indicating the magnitude of dot-deviation can show and quantify the deflection of a plarity of nozzles. The ratio of orifice diameter to thickness determines the drop velocity V_{drop}, and a high enough V_{drop} provides a low deflection inkjet. The asymmetry perturb around the orifice seriously degrades drop-ejected accuracy. Therefore, any factor resulting in defect or perturb around an orifice, such as cloggy ink, uncircular orifice must be eliminated. An accurate and high-quality printing should be approached.

References

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Biographies

Opto-Electronics & Systems Laboratories, Industrial Technology Research Institute (**OES/ITRI**) was engaged in designing and developing inkjet technology since 1995 and always stood a foremost position in Taiwan. We have developed a variety of inkjet chips, orifice plates, bonding tapes, black/color ink and cartridges already and led them to be manufactured. Now we concentrate on the optimization of the printheads with high resolution and high printing speed, and pay the effort to investigate the feasibility of applying liquid-jet technology to the other fields.

Chien-Hung Liu jointed the Print Head Development and Manufacturing Section of OES/ITRI in 1999. He received his M.S. and Ph.D degree from Institute of Electronics of National Chiao-Tung University, Taiwan. His interest lies in the design and integration of inkjet head. He is the section manager. E-mail: LIUCH@itri.org.tw

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Chun-Jung Chen jointed the Printing Department of OES/ITRI since 1990. His interest lies in the electronic photoimages. He is the department manager.

Figure 8. The photographical image of dots printed-out actually by type NZ-A with 36 nozzles (2 dots lost).

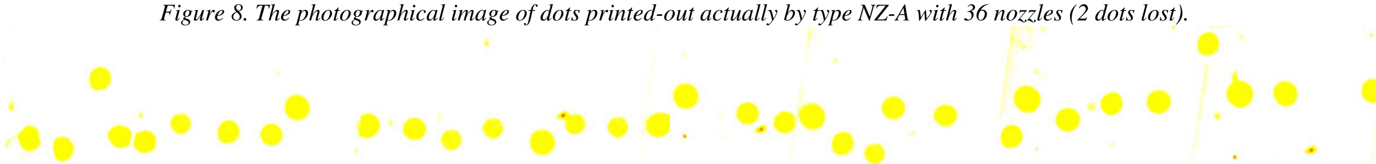

Figure 9. The photographical image of dots printed-out actually by type NZ-B2 with 36 nozzles (3 dots lost).