Cross-Talk of Multi-Nozzle in Electrostatic Inkjet System

Shinjiro Umezu, Ryosuke Nakazawa and Hiroyuki Kawamoto, Department of Mechanical Engineering, Waseda University, 3-4-1, Okubo, Shinjuku, Tokyo 169-8555, Japan

Abstract

We have been developing an electrostatic inkjet system for printers and mask-less electronic micro-circuit printing. The system consisted of a tube filled with ink and a plate electrode. When voltage was applied between the electrodes, a droplet was formed and separated at the tip of the tube periodically. Optimizing this system we have demonstrated 1,600 dpi printing on paper. However the print speed was deadly slow because this system had only single nozzle. Therefore we have been developing a multi-nozzle system that consisted of two parallel tubes filled with ink and the metal plate electrode. Three-dimensional calculation of the electric field was conducted by the Finite Difference Method to deduce the cross-talk between the electrodes and it is proposed that a new system that the waveform of the applied voltage was adjusted to cancel the cross-talk between the adjacent nozzle.

Introduction

It is well known that the electrostatic inkjet phenomenon is observed when a tube filled with ink is used for the pin electrode in the pin-to-plate system.[1] This phenomenon is expected to be applied not only for inkjet printing systems [2] but also for mask-less electronic micro circuit printing.[3] Because high quality and high speed are necessary for these applications. A Multi-nozzle head is suitable for the high speed system. However electrostatic cross-talk took place in the multi-nozzle system.

In this study, we have developed high quality inkjet system and investigated characteristics of cross-talk and droplet formation of the multi-nozzle system.

Demonstration of InkJet Printing Utilizing Single Nozzle

Experimental Set-up

An experimental set-up illustrated in Fig. 1 was constructed to investigate characteristics of the formation of droplets in the electric field. A tube filled with ink was mounted perpendicular to a plate electrode made of stainless steel. DC voltage was applied by a function generator (Iwatsu, Tokyo, SG-4105) and a high voltage amplifier (Matsusada Precision Inc, HEOP-10B2). The formation of the droplet was observed with a high-speed microscope camera (Photron Inc., Japan, FASTCAM-MAX 120K model 1) with a light (Sanei Electric Inc., Japan, XEF-501S).

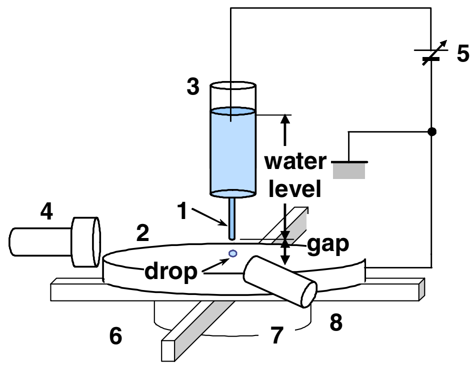

Figure 1 *Experimental set-up of single nozzle inkjet system. (1: water pin electrode, insulative capillary tube filled with ink, 2: metal plate electrode, 3: ink tank, 4: high speed camera, 5: high voltage amplifier and function generator, 6: linear stages, x and y directions, 7: mechanical z-stage, 8: light)*

Mode of Drop Formation and Print Demonstration

Figure 2 shows the current-voltage characteristics of the water pin electrode. This figure indicated that the formation of the droplet was classified into the following three modes corresponding to the discharge modes. In MODE 1, the diameter of the drop was several times larger than that of the tube diameter and the drop period was long, more than a second. In MODE 2, a Taylor cone was formed at the end of the tube and the tip of the cone periodically separated from the cone to form a very small droplet of the order of several tens of microns in diameter. This MODE 2 is suitable for inkjet printing. In MODE 3, the Taylor

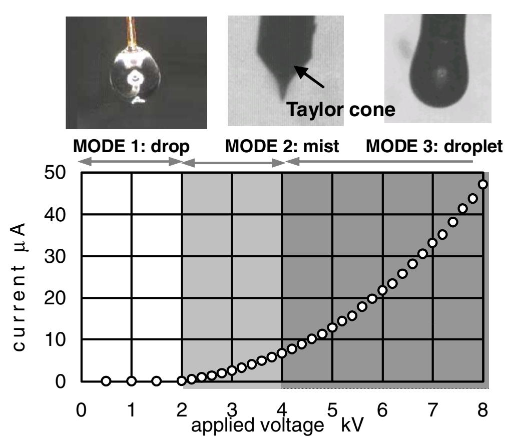

Figure 2 *V-I curves in pin-to-plate electrode system. (ϕ 100 μm inner tube diameter, ϕ 100 μm metal pin diameter, 3 mm air gap)*

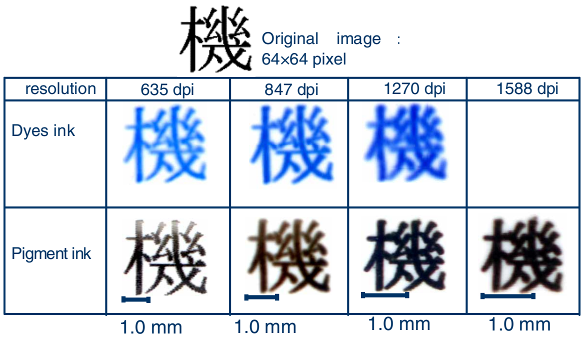

Figure 3 *Print samples. (tube outer diameter: 30 μm)*
Dyes ink: applied voltage: 1.2 kV
Pigment ink: applied voltage: 0.6 kV

cone changed to hemispherical and the droplet became relatively large, nearly the same as the tube diameter.

Figure 3 shows the print sample utilizing MODE 2 region. Maximum resolution of these samples was approximately 1550 dpi. It was demonstrated that this system was suitable for an inkjet printer. However, because this system had single nozzle, it took much time to demonstrate.

Multi-Nozzle in Electrostatic Inkjet System

Experimental Set-up

An experimental set-up illustrated in Fig. 4 was constructed to investigate a cross-talk effect of the multi-nozzle system. Two parallel tubes were placed perpendicular to the plate electrode. The interval between the centers of the tubes was 0.5 mm.

Cross-Talk of Multi-Nozzle

Figure 5 shows droplets in the case that DC voltage was applied to the single tube (right side) and the both tubes (left side). Droplets were moved in the repulsive direction of the other tube when common voltage was applied to the both tubes. Figure 6 shows the deviation of the droplet position from the center in case of the common voltage application to the both tubes. Droplet position was moved in the repulsive direction of the other tube under condition of the large gap. Because the Taylor cone was slanted behind of the other tube (Fig. 7) due to common voltage application to the tubes.

We investigated electrostatic cross-talk between the tubes. Figure 8, 9 and 10 show tips of the tube in the condition that

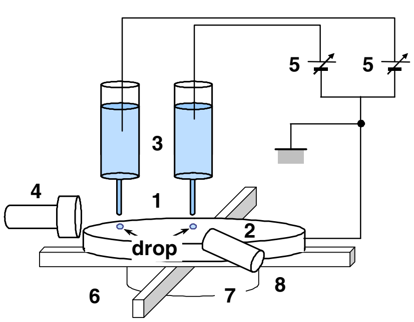

Figure 4 Experimental set-up of multi-nozzle inkjet system.

applied voltage to the adjacent tube was altered. In the case of the low voltage application to the adjacent nozzle, the Taylor cone was slanted towards the adjacent tube. In the case that the voltage application to the adjacent nozzle was 1.5 kV, the Taylor cone was straight and droplets fell right under the tip of the tube. When the voltage application to the adjacent nozzle was further increased, the Taylor cone was slanted behind of the other tube.

Three-dimensional calculation by the Finite Difference Method was conducted to investigate the electric field around the tips of the tube. Calculation model was shown in Fig. 11. The electric field was calculated with the Laplace's equation (1). ***E*** is the electric field ($= -\nabla\phi$, ϕ: potential).

$$\nabla^2\phi = 0 \;(\boldsymbol{E} = -\nabla\phi) \quad (1)$$

Boundary and initial conditions are as follows.

$\phi = V_{ap} = 2.5\ kV$ on the main tube.

$\phi = V_{offset}$ on the adjacent tube.

$\phi = 0$ on the plate electrode.

Figure 12 show calculated electric field around the tips of the tube. The electric field at the tip of the main nozzle was high. Table 1 shows electric field at the outside edge and inside edge on the main tube. The electric field of the inside edge was higher than that of outside edge in case of the low voltage application to the adjacent tube. In the case that the voltage to the adjacent tube was about 1.5 kV, the electric field of the inside edge was as high as that of the outside edge. When the voltage to the adjacent tube was further increased, the electric field of the outside edge became high. Because high electric field was moved from the inside edge to the outside edge due to increase of the applied voltage to the adjacent tube, the Taylor cone was inclined.

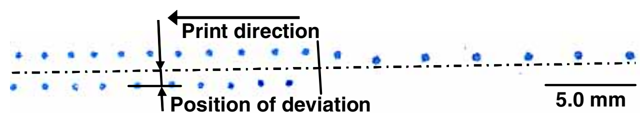

Figure 5 *Droplet lines utilizing multi-nozzle. (right side: voltage was applied to one electrode, left side: voltage was applied to the both electrodes)*

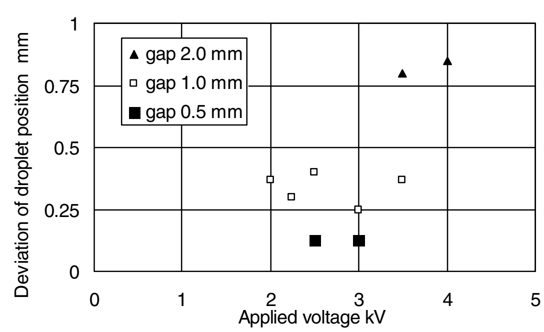

Figure 6 *droplet deviation on paper from the center .*

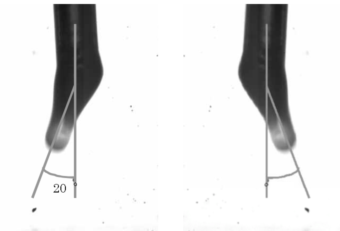

Figure 7 *photographs of the tip of the tubes. (2.5 kV was applied to the both tubes)*

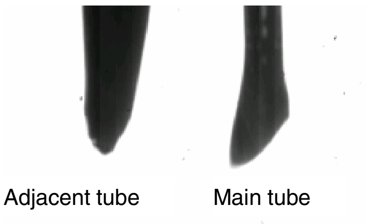

Figure 8 *photographs of the tip of the tube. (voltage of adjacent tube: 0.5 kV, voltage of main tube: 2.5 kV)*

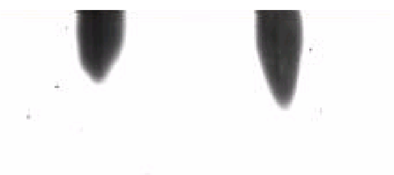

Figure 9 *photographs of the tip of the tube. (voltage of adjacent tube: 1.5 kV, voltage of main tube: 2.5 kV)*

Figure 10 *photographs of the tip of the tube. (voltage of adjacent tube: 2.0 kV, voltage of main tube: 2.5 kV)*

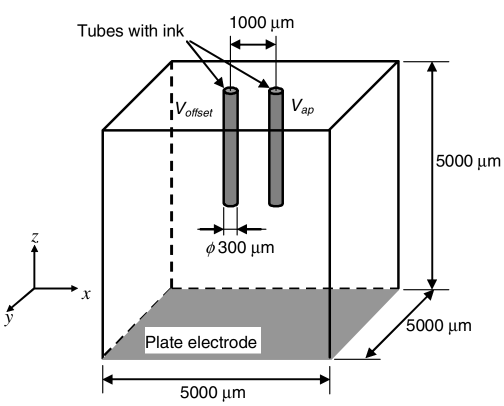

Figure 11 *Calculation model.*

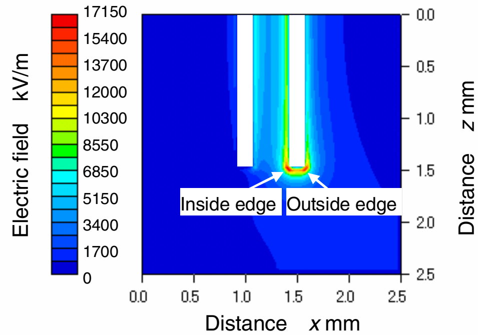

Figure 12 *Calculated electric field around the tube. (V_{offset}: 0.5 kV, V_{ap}: 2.5 kV, electric field of inside edge: 1.71×10^4 kV/m, electric field of outside edge: 1.42×10^4 kV/m)*

Table 1 Calculated electric field at the tip of the main tube.

Voltage on the adjacent tube	Electric field at the inside edge	Electric field at the outside edge
0.5 kV	*1.71×10^4 kV/m*	*1.42×10^4 kV/m*
1.5 kV	*1.40×10^4 kV/m*	*1.40×10^4 kV/m*
2.0 kV	*1.21×10^4 kV/m*	*1.35×10^4 kV/m*

Conclusion

We have developed high quality and high speed system utilizing electrostatic inkjet phenomena. Printing resolution of 1,600 dpi on paper was demonstrated utilizing the electrostatic inkjet phenomenon. However, because this system was deadly slow because only single nozzle was mounted, we have developed multi-nozzle system for high speed printing. Experimental and calculated result deduced that cross-talk between the adjacent nozzle was cancelled by the control of the waveform of the applied voltage.

References

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Author Biography

UMEZU, Shinjiro received the BE (2001) MS (2003)and Ph.D (2006) degrees in Mechanical Engineering from Waseda University, Tokyo, Japan. He is now a research associate in Mechanical Engineering at Waseda University, since September 2003. He awarded Best Presentation Award of the Japan Society of Mechanical Engineers in 2004. His research interests include imaging technology and MEMS technology utilizing electrostatic and gas discharge phenomena.