Study of the phenomenon of meniscus deformation and ejection by pulse voltage and frequency in drop-on-demand EHD printing

Sanguk Son, Kichul An, Yong-Jae Kim, Jaeyong Choi, Sukhan Lee

School of Information and Communication Engineering, Sungkyunkwan University, Korea, ssu2003@skku.edu

ABSTRACT

The phenomenon of meniscus deformation and ejection by various pulse voltages and frequencies in drop-on-demand EHD printing was investigated. To study the phenomenon of meniscus deformation and ejection, we measured the height of meniscus by the time of each pulse sequence. Result shows that restoration of meniscus height after pulse voltage has an important effect on the phenomenon of meniscus deformation and ejection in drop-on-demand EHD printing. A frequency increase, the droplet becomes smaller in the same voltage conditions. If pulse voltage increase, the droplet is increased at low frequency but pulse voltage increase, the droplet is decreased at high frequency.

Keywords: EHD, drop-on-demand, inkjet, printing

1 INTRODUCTION

EHD (electrohydrodynamics) printing has recently attracted attention for micro/nano size pattern devices due to it can make very small droplet than nozzle diameter and possibility of the use of various ink such as including metal, organic and bio material and high viscosity ink. EHD printing exist various ejection mechanisms, depending on the applied voltage and pressure, liquid property, nozzle materials and geometry [1-3]. Cloupeau and Prunet-Foch [4] describe various spraying modes that can appear depending on flow rate, liquid properties (surface tension, electrical conductivity and viscosity) and applied voltages. Several researchers investigated electrostatic drop-on-demand method using control the bias voltage and adding pulse voltage. Sato et al. [5] tried to modify or control the droplet formation process by adding ac voltage to a bias dc voltage. Also in some cases, the pulse voltage effects in electrospray on droplet size were investigated in previous works [6-8]. J.L. Li studied various phenomena of meniscus deformation by the pulsed voltage superimposed to a bias voltage [9-10].

Specially, a study on the applied voltage and frequency is important for reliable high-speed printing in drop-on-demand EHD printing. However, most of studies based on repetitive specific conditions of meniscus deformation and ejection was investigated. In fact, when pulse voltage was superimposed on the bias voltage, initially, symptoms appear unstable. Therefore, understanding this phenomenon is important to establish the drop-on-demand EHD mechanism. In this paper, we use the height of meniscus by the time of each pulse sequence were studied the phenomenon of meniscus deformation and ejection by various pulse voltages and frequencies.

2 EXPERIMENTAL SETUP

Fig. 1 shows the schematic of experimental set-up for drop-on-demand EHD printing using hard metal nozzle. The hard metal nozzle fabricated based on EDM technology and outer diameter is 200um. Liquid used in the present study was commercialization solvent pigment ink (InkTec Co., Ltd., K 300). The surface tension coefficient and the viscosity of the solvent ink are 30–32 dynes/cm and 10–12 cps at 25±5°C. The liquid have been supplied to the hard metal nozzle with constant pressure of 0.3kpa by constant pressure system. In order to capture meniscus deformation and ejection motion, high speed camera (Photon APX) at 15000 frames a second and 256 × 512 pixel resolution with a micro-zoom lens and a LED light source were used. A high voltage amplifier (maximum voltage of 3.0 kV) is used with a relay switch to control the electrostatic field. This nozzle was held in assembled inkjet head, and ground electrode plate was placed 1.2mm away from, the nozzle tip. The electric voltage signal applied to a hard metal nozzle electrode against ground electrode plate. In this work, the bias voltage was fixed at 0.4 kV and one single square pulse with a fixed width of 500us was superimposed on the bias voltage. Signals were produced by a function generator and then transferred to high voltages by the switch. The shape of the pulsed voltage was measured by the oscilloscope.

![Figure 1: The photograph of (a) hard metal nozzle, (b) experimental set-up for drop-on-demand EHD printing](image-url)
3 RESULTS AND DISCUSSION

To study the phenomenon of meniscus deformation and ejection by drop-on-demand ejection, we tested the deformation of meniscus shape by various applied DC voltage, as shown in figure 2. Because, stable drop-on-demand ejection need the suitable condition such as condition of bias voltage for maintaining a stable meniscus shape and pulsed voltage for optimal ejection. As shown in the results, a stable bias voltage is 0.4kv.

Pulse voltage (1.2kv) is lower than the onset voltage, after meniscus oscillation by pulse voltage, meniscus height at next bias voltage increases higher than the initial conditions (fig.4). However, due to the low frequencies, the height of meniscus is restored before the next pulse voltage is applied. Thus, the oscillation is repeated by the periodic pulse voltage. Pulse voltage (2.0kv) is higher than the onset voltage, after ejection by pulse voltage, meniscus height at next bias voltage decreases lower than the initial conditions (fig.5). Unlike the case of oscillation when the ejection is occurred, due to excessive decrease of meniscus height by 1st pulsed voltage, the meniscus height has not been fully restored. But, certain meniscus height is restored before the next pulse voltage. Since then, based on the height, ejection, reduction, restoration of the periodic pulse voltage is generated by the stable. If the frequency is slow enough, the height of the meniscus between the first and second pulse voltage will be handled in the fully restored.

Figure 2: Image of meniscus deformation and ejection due to the applied DC voltage.

Fig. 3 shows the three cases of meniscus deformation and ejection by difference of applied pulse voltage at drop-on-demand ejection. The ideal case, after ejection by optimal pulse voltage, referred to simply as onset voltage, the shape of the meniscus at next bias voltage is the same as the initial bias. Pulse voltage is lower than the onset voltage (case1), after oscillation, meniscus height at next bias voltage increases higher than the initial conditions. Pulse voltage is higher than the onset voltage (case2), after ejection, meniscus height at next bias voltage decreases lower than the initial conditions.

3.1 Meniscus deformation and ejection at Low frequency

To study the phenomenon of meniscus deformation and ejection, we measured the height of meniscus by the time of each pulse sequence. A fixed state of a meniscus by a constant bias voltage (0.4kv), the pulse voltage is applied to the meniscus height has changed, as shown in figure 4-5.
Figure 6 shows the effect of pulse voltage at low frequency. When increasing the pulse voltage, the difference between meniscus height in bias voltage conditions and meniscus height after pulse voltage conditions are increasing. This is shown in Figure 7, pulse voltage increase, the reduction of meniscus height after the 1st pulse voltage increase, but after this, certain meniscus height is restored before the next pulse voltage. In other words, if pulse voltage increases, reduction of meniscus height after pulse voltage base on certain meniscus height on bias voltage increase, but is restored to the same height before the next pulse voltage. This result shows that pulse voltage increase, the droplet is decreased at high frequency.

![Figure 6](image1.png)

**Figure 6**: Meniscus deformation and ejection by increasing pulse voltage at low frequency

![Figure 7](image2.png)

**Figure 7**: Meniscus deformation and ejection mechanism by increasing pulse voltage at low frequency

### 3.2 Meniscus deformation and ejection at High frequency

In case of high-frequency, as shown in Figure 8-9, after oscillation or ejection by pulse voltage, meniscus height is not restored. Because, that is the next pulse voltage apply before restoring the height of the meniscus. Pulse voltage (1.2kV) is lower than the onset voltage, after meniscus oscillation by pulse voltage, meniscus height at next bias voltage increases higher than the initial conditions (fig.8). However, due to the high frequencies, the height of meniscus is not restored before the next pulse voltage is applied. Thus, meniscus height is continuously increasing by a series of pulse voltage. In the end, ejection occurs when the appropriate conditions of meniscus height and pulse voltage are satisfied. In Figure 9, as a condition of high frequency and high pulse voltage case, unlike the case of low frequency and high pulsed voltage case when the ejection is occurred, due to excessive decrease of meniscus height by 1st pulsed voltage, the meniscus height has not restored. And, certain meniscus height is maintained before the next pulse voltage. Also, based on the height, stable ejection by the periodic pulse voltage is generated. At this point, meniscus height in bias voltage conditions and meniscus height after pulse voltage conditions almost dose not changed. Therefore, frequency increases, the droplet becomes smaller in the same voltage conditions.

![Figure 8](image3.png)

**Figure 8**: A case 1 in, the phenomenon of drop-on-demand EHD Printing at low pulse voltage, high frequency

![Figure 9](image4.png)

**Figure 9**: A case 2 in, the phenomenon of drop-on-demand EHD Printing at high pulse voltage, high frequency
Figure 10 shows the effect of pulse voltage at high frequency. When increasing the pulse voltage, both the meniscus height in bias voltage conditions and meniscus height in pulse voltage conditions are decrease. This is shown in Figure 11, pulse voltage increase, the reduction of meniscus height after the 1st pulse voltage increase, and after this, the meniscus height has not restored before the next pulse voltage. In other words, if pulse voltage increases, meniscus height on bias voltage is gradually decreased, and lower meniscus height is maintained before the next pulse voltage. In addition, the pulse voltage increases, although meniscus height in bias voltage conditions and meniscus height after pulse voltage conditions almost dose not changed and ejection occurs at lower meniscus height. Through this, the amount of ejection may be expected to decrease gradually. This result shows that pulse voltage increase, the droplet is increased at low frequency.

![Graph showing meniscus deformation and ejection by increasing pulse voltage at high frequency.](image)

**Figure 10:** Meniscus deformation and ejection by increasing pulse voltage at high frequency

![Diagram for EHD Printing at high frequency.](image)

**Fig. 11:** A case in the phenomenon of drop-on-demand EHD Printing at high frequency

## 4 CONCLUSIONS

We investigated the height of meniscus by the time of each pulse sequence at various frequencies. Result shows that restoration of meniscus height after pulse voltage has an important effect on the phenomenon of meniscus deformation and ejection in drop-on-demand EHD printing. If a low frequency, after oscillation or ejection by pulse voltage, meniscus height at bias voltage before the next pulse voltage is restored. But, if a high frequency, after oscillation or ejection by pulse voltage, meniscus height is not restored. So, a frequency increase, the droplet becomes smaller in the same voltage conditions. And pulse voltage increase, the droplet is increased at low frequency but pulse voltage increase, the droplet is decreased at high frequency.

In particular, required for reliable high speed printing in EHD printing, the printing of high frequency, has confirmed the importance of restoration of meniscus.

## 5 ACKNOWLEDGMENT

This work was carried out for the Direct Nano Pattern Project supported by the Ministry of Knowledge Economy under the National Strategic Technology Program.

## REFERENCES


