Pulse Control Characteristics of Jumping Conductive Toner by a pair of Aperture Electrode

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Abstract

Toner cloud beam (TCB) is a novel toner-based printing method that employs conductive toner. Toner dots are formed directly on paper in the TCB method. The toner beam is controlled by applying a pulsed voltage to a pair of aperture electrodes. The pulse control characteristics of the toner beam are important in the TCB method. The dot formation dependence on the electrode voltages is investigated experimentally and the relationship between the dot size and the pulse duration is obtained. An enlarged model with an aperture diameter of 0.5 mm is used to confirm that dots are formed in less than 10^{-4} s. The toner speed at a toner cloud generation voltage of 550 V is estimated to be 4.1 m/s.

Introduction

Toner-based printing technologies have several attractive characteristics including the ability to print on plain paper at high speeds and with high quality[1~4]. Electrophotography is the most important toner-based printing technology and it has become mainstream technology in offices. Electrophotography has advanced greatly and it is currently used in a wide range of applications ranging from personal use to high-speed, high-volume printing. Electrophotograpic printing consists of six processes; it is expected to be simplified in the future. Several simple toner-based printing processes have been proposed. Of these, TonerJet® is a well-known, simple printing process. Printers have been developed that employ this printing process[5] and a compact prototype color printer has been developed[6]. Another simple printing mechanism that uses conductive toner has been proposed[7].

Toner cloud beam (TCB) is a simple printing process that employs conductive toner. It forms toner dots directly on paper by applying a pulsed voltage to a pair of aperture electrodes[8-10]. Previously studies[11-15] have experimentally investigated the factors that affect dot formation in TCB; they found that dot formation is affected by the applied voltage, the distance between the two electrodes, and the aperture electrode thickness. These studies investigated the effect of pulse duration on dot formation; however, greater understanding of dot formation at short pulse widths is required.

In the present study, we investigate pulse control using a pair of aperture electrodes to understand dot formation at short pulse widths. The effects of pulse duration for short pulses and the voltage applied to the electrodes on dot formation are examined.

Experimental

Fig. 1 shows a schematic diagram of the TCB experiment. The experimental toner control system in Fig. 1 consists of four electrodes: upper and lower electrodes and a pair of aperture electrodes. Voltages are applied to each electrode. The voltages applied to the upper and lower electrodes are designated TJ and TP, respectively. A voltage pulse is generated by amplifying the signal from the pulse generator. The voltage pulse is then applied to the upper aperture electrode GC. The amplifier is a high-speed bipolar amplifier (NF, HSA4051). A function generator (NF, DF1905) is used to generate pulses. The aperture electrode is made from stainless steel (SUS304); a 0.5-mm-diameter aperture is drilled in its center. The toner particle size is 8~11 μm and the resistance of the toner is 1.5×10^{8} ·cm. Coated paper (Oji Paper Company) is used for printing.

There are two states (see Fig. 2): an 'off' state in which toner cannot pass and an 'on' state in which toner can pass. In this experiment, the toner is controlled between the 'on' and 'off' states. The 'on' state is realized by applying a pulsed voltage to the GC electrode (see Fig. 3).

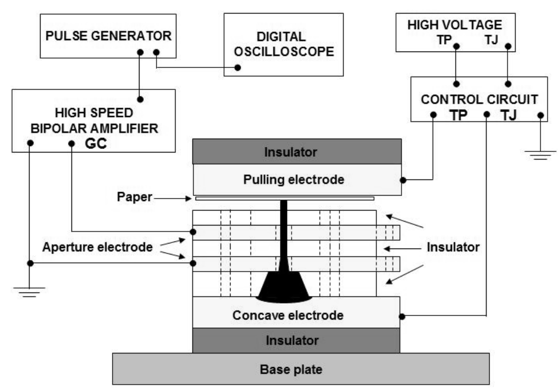


Figure 1. *Schematic diagram of the TCB experimental system.*

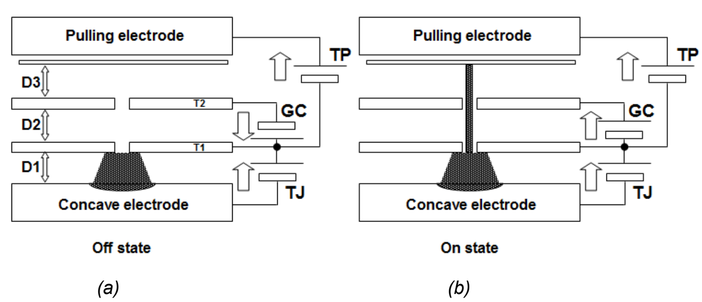


Figure 2. *States of TCB, a) Off state, b) On state.*

Table 1 lists the experimental conditions. A negative voltage is applied to GC to prevent the toner passing the aperture electrode. The voltage TJ is applied to the lower electrode to generate a toner cloud between the lower electrode and the lower aperture electrode. The TP voltage is then applied to the upper electrode as the pulling voltage. When the GC voltage is changed to a positive pulsed voltage and if the control pulse duration is longer than toner traveling time between a pair of aperture electrode, the toner will pass through the aperture electrode to form a dot on the paper.

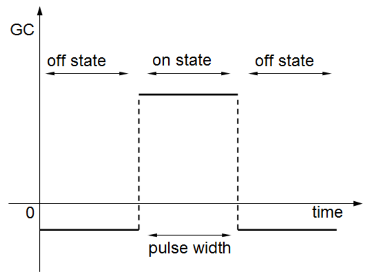
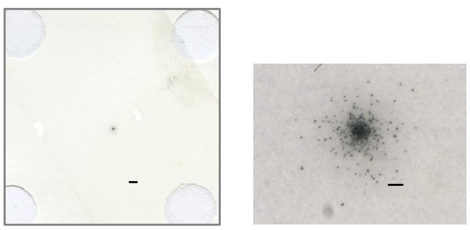


Figure 3. *Time dependence of GC.*



(a) *(b)*

Figure 4. *Typical images of dots: a) dot image, b) image enlarged by a factor of 10.*

Table 1. *Experimental conditions.*

Variable	Value
TP	450 V to 750 V
GC (on)	200 V~300 V
TJ	-400V to -550 V
Ø	0.5 mm
D1,D2,D3	0.5 mm

Results and Discussions

1. Dependence on toner jumping voltage TJ

In this experiment, the dependences of the dot size on the pulse duration were investigated by varying the TJ voltage in the range -400 V to -550 V. The GC and TP voltages were kept constant at 250 V and 750 V, respectively. Fig. 4 shows an example of an image of a dot; Fig. 4(a) shows the dot image and Fig. 4(b) shows the same image enlarged by a factor of 10.

Fig. 5 shows the experimental results obtained. It reveals that above certain threshold pulse duration the dot size increases as the pulse duration increases. The dot size increases and the dot formation threshold shifts to a shorter pulse duration when the TJ voltage is increased.

The increase in the dot size with increasing pulse duration is considered to be due to more toner reaching the paper. The reduction in the threshold pulse duration is thought to be because the time required for toner to pass between the aperture electrodes decreases, since the toner will not pass through the aperture electrodes if the pulse duration is less than the time required by the toner to pass through the aperture electrodes. Concerning the toner jumping (TJ) voltage, the toner velocity is considered to increase as the TJ voltage increases. Thus, the threshold pulse duration decreases and the dot size increases. The TJ voltage causes the toner to jump; if it becomes too high, it is difficult to realize the 'off' state. Consequently, it is important to determine the optimum TJ voltage.

2. GC voltage dependences

Fig. 6 shows the dependences of the dot size on the pulse duration for GC voltages of 200 V, 250 V and 300 V. The TJ and TP voltages were kept constant at -550 V and 750 V, respectively. Fig. 6 shows that the curves shift to shorter pulse durations in the small dot region as the GC threshold voltage for the 'on' state increases. This implies that the toner is able to pass through the aperture electrodes in a shorter time as the GC voltage increases.

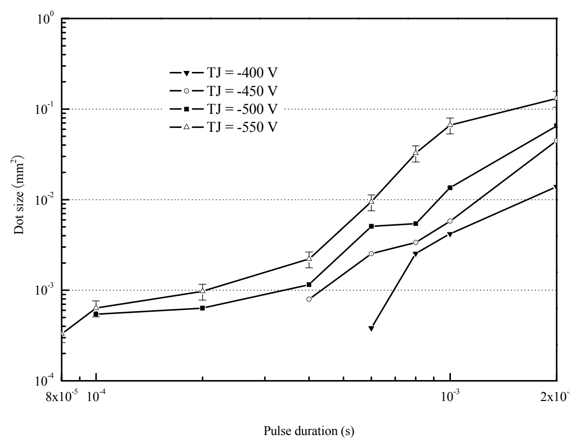


Figure 5. *Dependences of dot size on pulse duration plotted on a log scale for four different TJ voltages.*

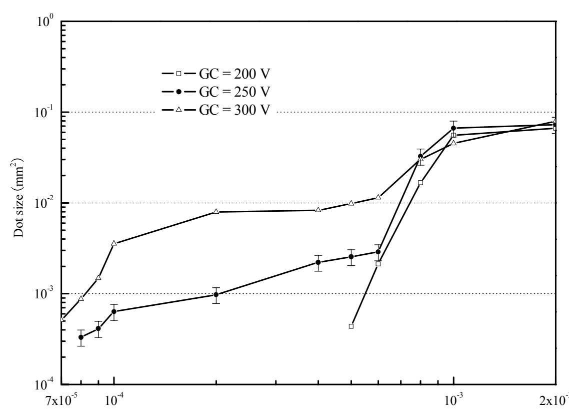


Figure 6. *Dependences of dot size on pulse duration plotted on a log scale for three different GC voltages.*

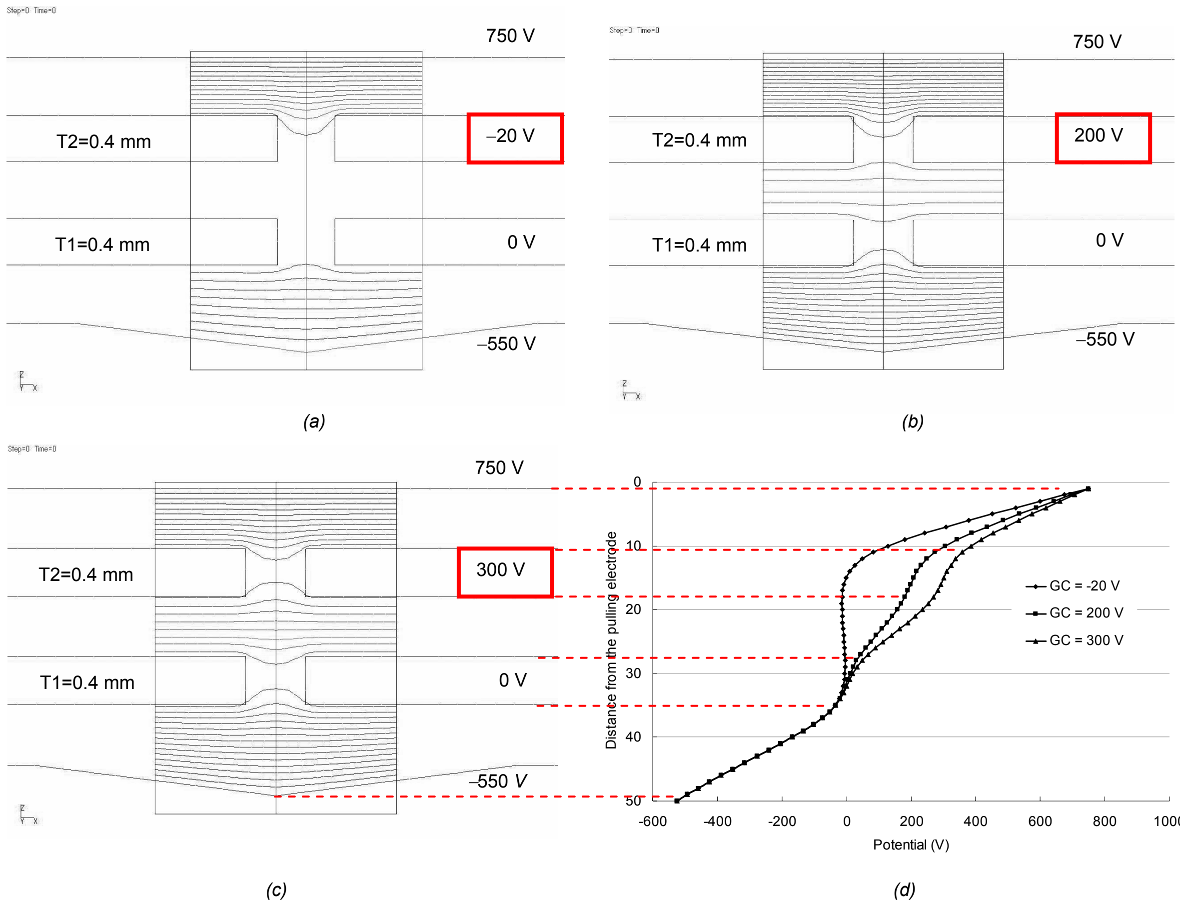


Figure 7. *Analyzed results of potential for (a) off and (b) on states when GC is 200 V, (c) on state when GC is 300 V, equipotential line are shown, (d) potential at the central axis when GC voltage is -20, 200, and 300V.*

Figs. 7(a)-(c) show the results of the electric field analysis near the aperture electrodes for GC voltages of -20 V, 200 V and 300 V, respectively. Fig. 7(d) shows the potential at the central axis of the aperture. The potential change slope, which is proportional to the electric field used to control the toner speed, increases as the GC voltage increases. Thus, toner can pass through the aperture electrodes in a shorter time as the GC voltage increases.

3. TP voltage dependences

Fig. 8 shows the dependences of the dot size on the pulse duration for four different TP voltages between 450 V and 750 V. The TJ and GC voltages were kept constant at -550 V and 250 V, respectively. Fig. 8 shows that the curves shift to shorter pulse durations in the small dot region as the TP voltage increases. The dot size varies little when the TP voltage is in the range 550 V to 750 V and the pulse duration is in the range 0.4×10^{-3} s to 2×10^{-3} s. The toner is thought to pass through the aperture electrode more readily as the TP voltage is increased. The amount toner that passes through the electrode may increase with a TP voltage of 550 V ~ 750 V; however, the dot size does not increase. This is because toner concentration along the central axis intensifies with an increase in the TP voltage.

4. Toner speed estimation

The toner speed between the aperture electrodes is important in this printing process. The toner speed is estimated approximately. Toner is considered not to be able to pass through the aperture electrodes when the pulse duration of the 'on' state is shorter than the time toner travels between the aperture electrodes. The amount of toner that passes through the aperture electrodes is proportional to the difference between the toner travel time and the pulse duration. Fig. 9 shows the relationship between the dot size and the pulse duration. The pulse durations at which dots start to be formed on paper are 5.7×10^{-4} s, 3.5×10^{-4} s and 2.2×10^{-4}s for TJ voltages of 450 V, 500 V and 550 V, respectively; from these pulse durations, the toner speeds are estimated to be 1.6 m/s, 2.6 m/s and 4.1 m/s, respectively. Thus, the toner speed increases as the TJ voltage is increased. This is because the charge induced on the toner and the accelerating electric field both increase when the TJ voltage is increased.

Conclusions

Pulse control characteristics of toner beam by aperture electrodes are investigated. The dependences of the characteristics on three voltages for generating toner cloud, controlling toner passing through apertures and toner pulling from aperture electrode are experimentally obtained. It is found that the dot is generated in shorter pulse duration as these voltage increases and dot is generated less than 10^{-4}s. It is also found that the travelling speed of toner increases as the voltage for toner cloud generation and that the speed is roughly 4.1m/s at a toner jumping voltage of 550 V.

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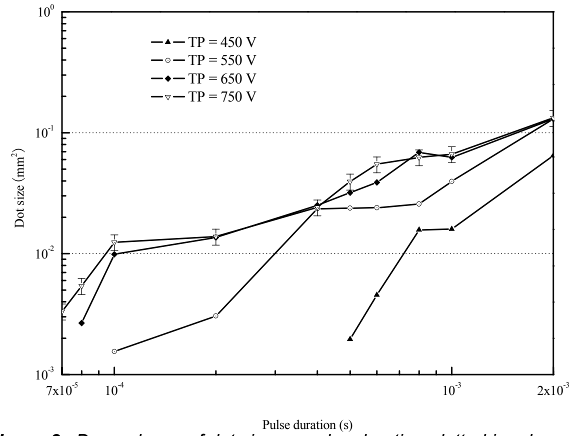

Figure 8. *Dependence of dot size on pulse duration plotted in a log scale for four different TP voltages.*

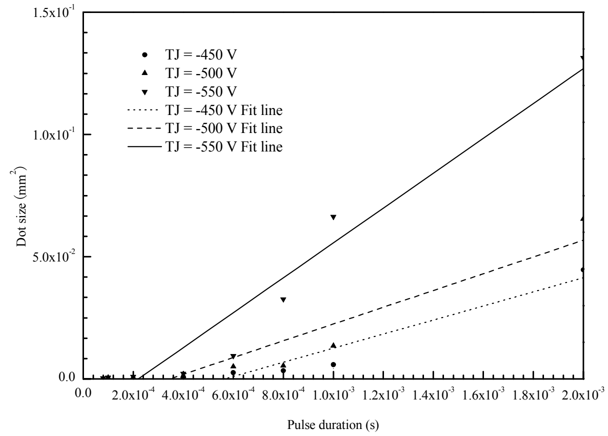

Figure 9. *Dependence of dot size on pulse duration for three different TJ voltages.*

Author Biography

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