CHAPTER 2

THEORETICAL BACKGROUND AND LITERATURE REVIEWS

2.1 Theoretical Background

2.1.1 Digital Printing

Digital printing or Computer-to-Print depends on a digital front-end system that can scan originals, creating text and images on electronic media. The printing process, from the capture of live or still originals, proofing, and printing, can be done electronically without the need for conventional film, plate, proof or printing press. Comparison of digital printing with conventional offset printing shows the reduced number of stages involved as digital files go directly from the creator to press.

- Conventional offset printing

Electronic page layout → output film → color proofs → stripping → plate making → printing → finishing

- Digital printing

Electronic page layout → printing → finishing.[2]

Digital printing is any reproduction technology that receives electronic files and uses spots (or dots) for replication. Ink, toner, inkjet or any dye- or pigment-based transfer system may be used.

Digital printing also refers to the use of a re-imagable carrier or no image carrier for the transfer of toner or inkjet ink to paper. Inkjet is a direct-to-paper technology with no intermediate image carrier. Toner-based reproduction requires a drum or belt to create the toned image and then transfer it to paper. In essence, the drum acts as an image carrier. The toner-based image carrier must create a new image for every reproduction and is thus re-imagable. Short-run printing, which is the domain of conventional printing presses, is undergoing significant change with the emergence of digital presses based on electrophotographic technology.

Personalization and short runs are the important advantages of digital printing. Other advantages are print on-demand and just-in-time printing. Digital printing is utilized in variable printing and new presses because they save cost and time compared to conventional offset printing.[3-5]

2.1.2 Toner-Based Systems

Toner-based systems of printing are unique in the fact that they use a dry plastic powder called toner, which is fused to the paper with heat. The first forms of toners were used in 1938 when Chester F. Carlson invented an electrostatic process that reproduced words on a page in just minutes called xerography (also well known as electrophotography). Since then, great improvement of toner-based printing system has been accomplished.

According to the process of reproduction image, there are five main types of toner printing systems. They can all be computer driven and they use optical or electrical techniques in order to form the latent image to which toner may be attracted. These are electrophotography, ion deposition, electrostatic, magnetographic and electrophotographic. The most important and widely use is electrophotography.[2] This research work involves electrophotographic and electrostatic aspects.

2.1.3 Electrophotography

Electrophotography, the technical name for photocopy and laser printing, is a technology that uses electricity to reproduce images. The process of electrophotographic printing relies on six basic steps, which includes charging, exposing, developing, transferring, fusing and cleaning. The process of electrophotography is shown in Figure 2-1 and described in following items (a-f).

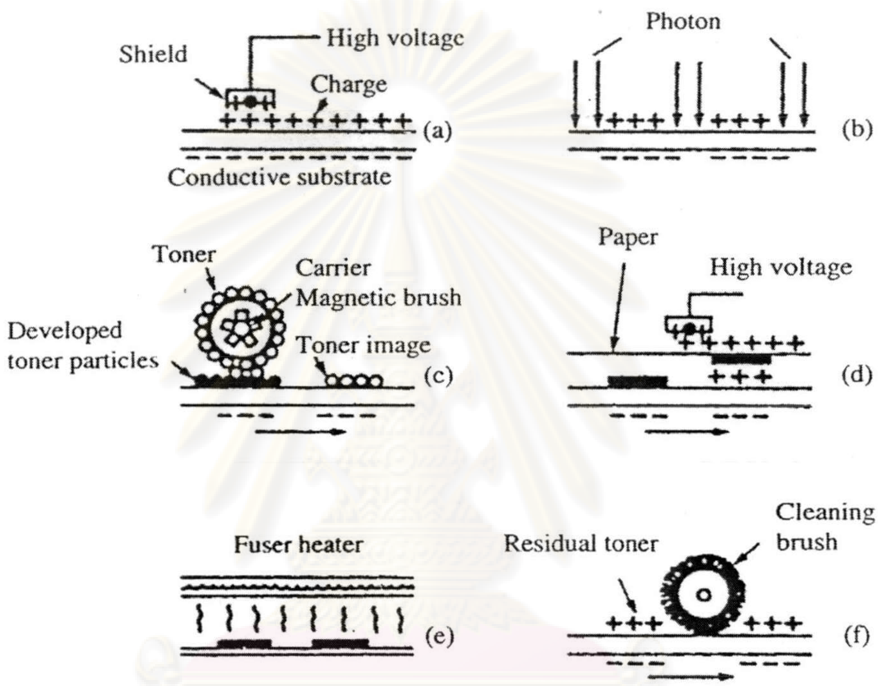


Figure 2-1 Six basic steps in electophotographic reproduction

a) In the charging step, a uniform electrostatic charge is applied to the photoconducting layer on the printing drum through the use of wire or grid bias to high voltage.

b) In the exposing step, light is projected onto the photoconducting layer in the non-image area. The photoconducting layer is sensitive to light which causes the charge in non-image area is neutralized when the light touches. This step produces a "latent electrostatic image" in the shape of the original image on the drum.

c) In developing step, the latent image is covered in some form of toner (either dry or liquid). The toner must have the opposite charge to the non-exposed area in order to adhere to the latent image.

d) In the transferring step, a sheet of paper is inserted into the machine. The charge on the drum is reversed, which causes the toner particles to repel away from the drum and onto the paper.

e) In the fusing step, dry toners are then fused to the paper with heat or pressure. Liquid toners are fused after drying.

f) In the cleaning step, the drum is brushed to remove excess toner, and then exposed to light to remove any lingering image or charges.

2.1.4 Toner jet

A new electrostatic technology is that of Toner jet. Array Printers AB in Sweden invented this technology in 1986. Toner jet is a direct print process where the image is formed directly onto the print media e.g. paper or belt. The configuration of the Toner jet print head is shown in Figure 2-2. The toner particles (negative by charged) are repelled from a toner sleeve to the print media by electrostatic forces created by a potential difference between a toner sleeve and a back electrode that is located behind the print media. The flexible print circuit board or FPC with arrays of microscopically fine holes as shown in Figure 2-3 is located between a toner sleeve and a back electrode. Each hole of FPC is surrounded by a ring electrode that is connected to a printer controller via a high voltage driver. If the electrostatic field created by the toner sleeve and the back electrode is strong enough to shoot the toner particles through the holes and onto the paper, then the toner image is formed. This can be prevented by changing the electronic potential on the ring electrodes surrounding the holes of FPC. Thus, with a standby potential, no toner passes onto the paper and no dot reproduction on the print media.

Then, the document is fused in the same manner as in laser printers; heat and pressure cause the toner to bond to the paper. Meanwhile, the FPC is cleaned and the next page is ready to be printed.[1,6]

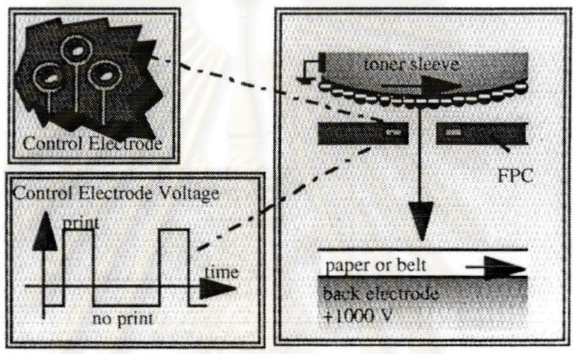


Figure 2-2 The control electrode in the FPC controls the toner transfer through the aperture

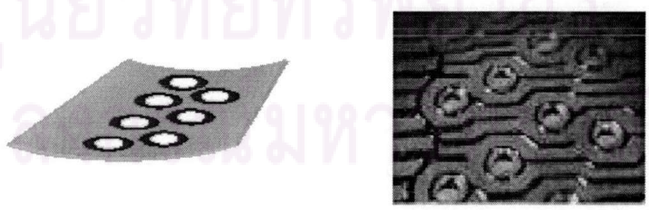


Figure 2-3 Flexible printed circuit board (FPC) with rows of apertures and ring electrodes

Toner jet, which relies on the mono-component toner, thereby, accomplishes in three steps, whereas the laser technology needs six steps to do the same job. Toner jet thus processes a competitive advantage in this respect.

2.1.5 Toner Cloud Beam (TCB)

In 1999, Hoshino and Hirayama[7] proposed a new dot formation method for the toner-based digital printing system called Toner Cloud Beam (TCB). This method has an advantage that the printing mechanism is simplified compared with the electrophotography and TCB differences from Toner jet in that it relies on conducting toner while Toner jet relies on insulating toner. The basic theory for the dot reproduction in TCB technology is described in the following items (a-c).

a) Toner cloud generation condition

To generate a toner cloud, the experiment for the toner jumping as shown in Figure 2-4 is setup. The system consists of two closely spaced conducting parallel plates placed across, a voltage source are connected for applying the voltage to the electrode, and an electrometer for the current measurement. Firstly, conducting toner particles are deposited on the top surface of the bottom electrode. Next the dc voltage is applied to the electrodes. The voltage is ramped from zero to a maximum voltage at a constant rate. In this procedure, the toner particles are charged. When the electrostatic force of detachment exceeds the forces of adhesion between the toners and substrate, the toner particles jump from the lower electrode to the upper electrode and these cause an increase of current between the two parallel plates. After reaching the upper electrode, the initial induced charge is neutralized and the particles acquire electrostatic charge of the opposite polarity, and then move toward the lower plate. These fallen particles are charged again and repeat same behavior until the applied voltage is stopped or they move out of the system. According to Hosino and his co-workers, the total current can be written as follows:

$$I = I_c + I_t \tag{2.1}$$

whereas I_c is the current through the parallel plate capacitor given by:

$$I_c = C\frac{dV}{dt} \tag{2.2}$$

where C is capacitance of the measuring cell and $\frac{dV}{dt}$ is the rate of a voltage increment. I_t is the current generated by the toner jumping between the two parallel plates.

When one of the toner particles begins jumping from the lower electrode to the upper electrode, the following relationship is valid:

$$\vec{F_e} = \vec{F_a} + \vec{F_g} \tag{2.3}$$

where $\vec{F_e}$ is the electric force, $\vec{F_a}$ is the adhesion force and $\vec{F_g}$ is the gravitational force. Alternatively, the electric force $\vec{F_e} = Q\vec{E}$, when Q is the induced toner charge and $\vec{E}$ is the electric field.

The adhesion force between the toner particles and the substrate, $\vec{F_a}$, has two components that are electrostatic image force and the van der Waals force.

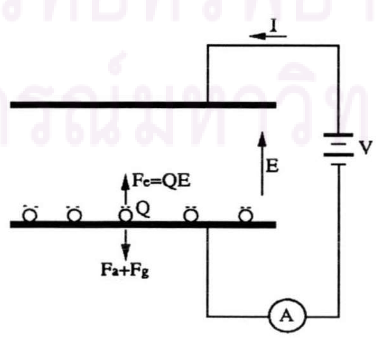


Figure 2-4 Schematic diagram of the experimental setup for the toner jumping

When the electric force overcomes sum of the adhesion force and gravitational force, the toner particles jump from the lower electrode to the upper electrode and cause an increasing in total current as shown in Figure 2-5. The voltage value at which the toner jumping occurs is called the threshold voltage, V_{th}.[8-10]

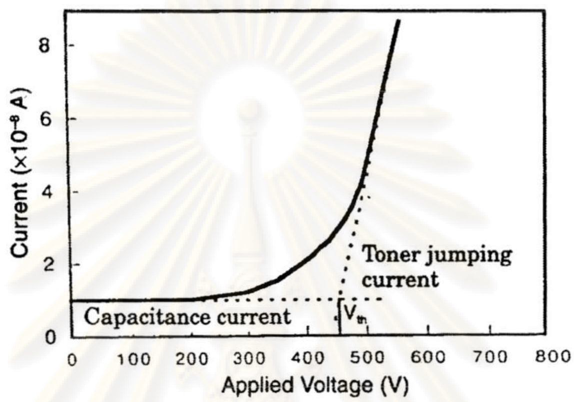


Figure 2-5 Determination of threshold voltage for toner jumping across the parallel plates.

b) Toner cloud confinement condition

In the experiment for the toner jumping, when the voltage applied to the electrodes increases from zero until it reaches the threshold voltage, the toner particles start to move up and down between the electrodes and these causes an increase in the measured current. The current waveform versus the ramp voltage applied between two electrodes is shown in the Figure 2-6 (a). Obviously, the current waveform drops down rapidly as a result of a moving out of toner particles.

To confine toner cloud, Hoshino and his co-worker replaced the flat lower electrode by the electrode that is dented to a thin lens shape as shown in Figure 2-7, and repeated the experiment.[11] The current waveform versus the ramp voltage applied between two electrodes is shown in the Figure 2-6 (b). The amplitude of the current waveform has a linear relationship to the amount of jumping toner in the condition of the same applied voltage. This shows that the conductive toner is confined between the electrodes at the dented area. The confinement is confirmed by observing the toner motion through the upper transparent electrode which is covered by a thin layer of indium tin oxide (ITO) glass. When the toner start jumping, the toner on the electrode goes out of sight and becomes like a black cloud in the dented area. The phenomenon is explained that the electric force lines have the direction toward the center axis as shown in Figure 2-8.

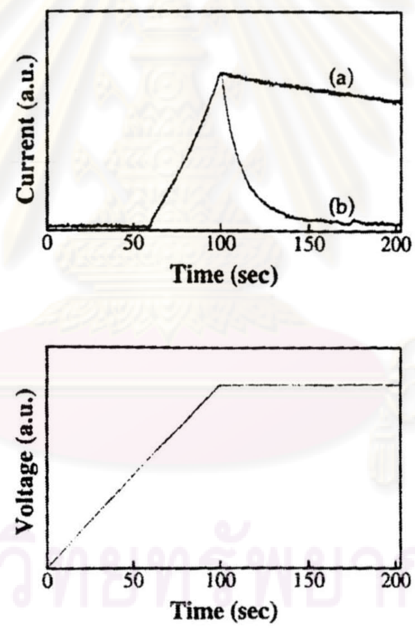


Figure 2-6 The current waveform versus the ramp voltage applied between the electrodes. The current waveforms (a) and (b) correspond to the dented electrode and the flat electrode, respectively.

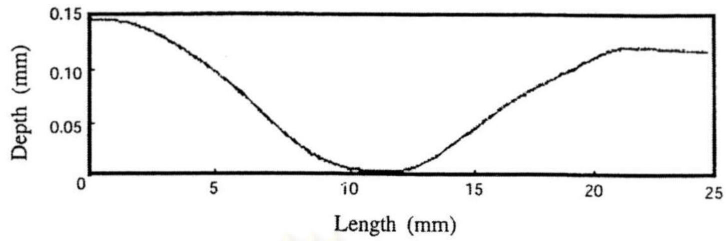


Figure 2-7 Cross section of the dented shape electrode

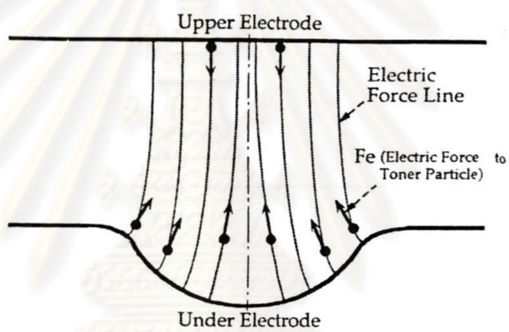
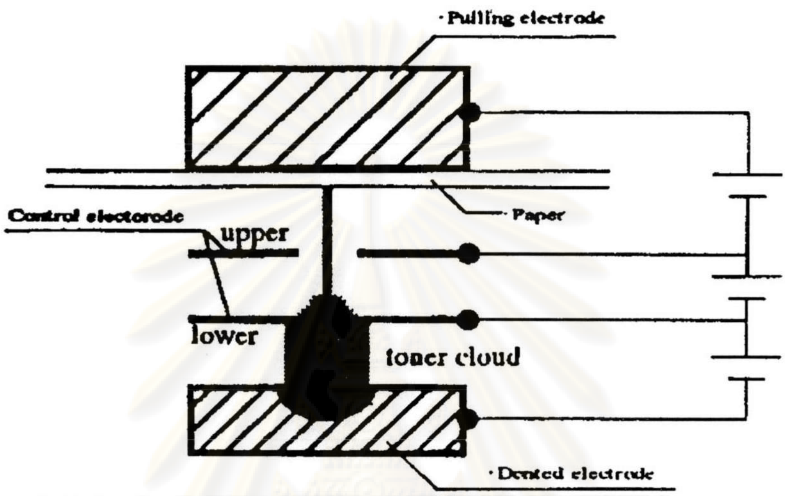


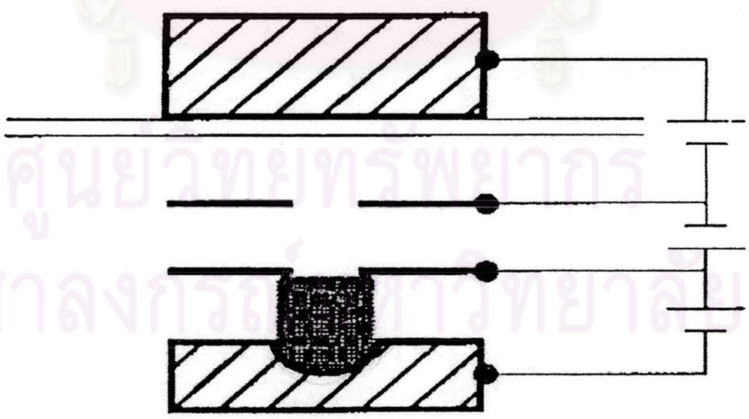
Figure 2-8 Schematic demonstration of the toner motion in the case of dented electrode

c) Control condition of Toner Cloud Beam

The experimental setup for a new dot formation method, Toner Cloud Beam (TCB), is shown in Figure 2-9.[7] In the system, a dented electrode, lower control electrode, upper control electrode and pulling electrode are placed parallel in the horizontal line, respectively, leaving a certain distance between them using insulating sheets. The dented electrode and the pulling electrode are used to generate toner cloud and confine toner cloud at the dented area. The toner movement is controlled by a switch of the electric field polarity between two control electrodes. By applying an extracting electric field to the toner cloud, the toner beam is extracted from the toner cloud and is project to paper. These procedures produce a toner dot on the paper.



(a) “on” state



(b) “off” state

Figure 2-9 Toner beam control mechanism

The toner beam is controlled as shown in Figure 2-9. For the on state case, the voltage applied to the upper control electrode is higher that the voltage applied to the lower control electrode and results in the negatively charged toner moves upward passing through the control electrode. In an opposite way, the off state means the voltage of the upper electrodes is less than the lower electrode. The toner cannot pass the control electrode because the direction of electric field in the aperture of control electrodes becomes blocking.

2.1.6 Toner Material

Toners, which essentially consist of pigment particle, thermoplastic resin and charge control agent (CCA), are the main coloring medium for digital toner printing systems. There are two major groups of toners that are dry toners and liquid toners.

Dry toners are classified into two main types including dual component toners and single- or mono-component toners.

Dual component toners are made up of two distinctive parts; toner and carrier bead which help transport and bind the toner to the substrate. There are three major ways of developing dual-component toners; cascade development, magnetic development and continuous tone development. They generally also have advantage over mono-component toners in that their particle size is smaller, yielding higher resolution and brighter printed colors.

Mono-component toners differ from dual-component toners in that they do not require the use of carrier bead for development. There are several ways to charge mono-component toners: induction, contacting, corona charging, ion beam and traveling electric field. Single component developer hardware is generally simpler, smaller and lower in cost than two-component developer hardware.

Liquid toners consist of pigmented toner and carrier which is normally a liquid hydrocarbon or mineral spirit. Liquid toner systems are generally considered to give superior printed results than dry toner systems, through brighter colors and smaller toner particle size.[2,4,12]

2.2 Literature Review

The basic of TCB printing involves with toner jumping characteristic, which is a property of conducting toner. In early research, the toner jumping property in electric field is investigated to understand the movement of electrostatically charged toner particles, which occur during the development, transfer, and cleaning step in copying machines and laser printers. Subsequently, this property became useful for invention of a new direct printing process called Toner Cloud Beam, TCB.

A method of estimating van der Waals force of adhesion between various substrates and toners, which involves the measurement of current to cause toner jumping between two conducting parallel plates.[8] There are three difference sizes of toners including small, medium and large size. There are three types of substrates used including stainless steel, silicon wafer and PPC paper. According to the experiment, conducting toners were first sprayed on the lower plate, then applied the ramped voltage to the plates at a constant rate. When the electrostatic force of detachment exceeded the force of adhesion between toners and substrate, there was a significant increase of current between the two parallel plates. The particles jumped from the lower plate and reach the upper plate. Then the threshold voltage was determined and the van der Waals force between the toner and test substrates was estimated. They found that the threshold voltage, for detachment of toners from the substrate, decreases with increasing particle size. The threshold voltage for toner jumping remains essentially the same for stainless steel and silicon wafer but when moist papers were used, the threshold voltage had to be higher for toner jumping start. Moreover, by changing the rate of increase of the voltage, it indicated that the charging time constant was less than the time required for electric field to reach its threshold value start from zero. The toner jumping experiment was applied to estimate toner adhesion force between various substrates and toner particle sizes.[9] Four conductive toner sizes were studied including large-to-large size (14.6 μm), large-to-medium size (12.5 μm), medium-to-large (9.43 μm) and medium-to-medium size (7.7 μm). The lower electrodes used were a crystalline silicon wafer, Organic Photoconductor (OPC), ITO coated glass and stainless steel. In addition, several toner application methods were tried including free falling, wipe-on using Kim-wipe and magnetic brush. Toner was first sprayed on one of a pair of electrodes. Voltage increase at a constant rate was applied to the electrodes. From the toner jumping voltage, the adhesion force was estimated. The conductive glass shows significantly different jumping voltage of the toner whereas the amorphous silicon film was inactive to the voltage applied and toners cannot jump. Using magnetic brushing technique, the threshold voltage is higher than Kim-wipe rubbing and free falling, respectively when the same type of lower electrode was used. Kiatkamjornwong et al.[9] results confirmed Hoshino et al[8] work, the smaller the toner size, the higher the toner jumping voltage. The influence of electrostatic and van der Waals forces to toner adhesion was further discussed by Fukuchi and Takeuchi[10], by comparing results of toner jumping method and centrifugal method. To measure the toner adhesion forces by the toner jumping method, a toner was spattered over on the lower electrode. The dc voltage applied to the electrodes was increased at a constant rate, and the occurrence of the toner jumping was observed by measuring the current flowing between the electrodes. The toner adhesion force was then estimated from the voltage at the occurrence of the toner jumping. The numbers of toner particles, which have a certain adhesion force, were estimated. In this research, low resistivity toners were used. The toner adhesion forces were distributed from 10^{-11} to 10^{-7} N. Fukuchi and Takeuchi[10] concluded that the results of the toner adhesion force measurements by the toner jumping method agree well with those by the centrifugal method. A new technology of powder control was proposed by Hoshino et al.[11]. This technology relies on the toner jumping method. The experimental setup is similar with the toner jumping experiment except that the bottom electrode is substituted with the electrode that is dented to a thin lens shape. The conductive toner is sprayed freely on the electrode. When more than a certain value of electric field is applied between the electrodes, the powder starts to move up and down between the electrodes by electrostatic force. The current between the electrodes is measured. The results show that the current has a linear relationship to the amount of jumping toner at the same voltage. These results led to the conclusion that the conductive power is confined between the electrodes in the dented area. The confinement is also confirmed by observing the toner motion through the upper transparent electrode. A new dot formation method called Toner Cloud Beam (TCB) was also invented by Hoshino et al.[7]. The experimental setup for this new dot formation method includes a dented electrode, lower control electrode, upper control electrode and pulling electrode, which are placed parallel, respectively, leaving a certain distance between them using insulating sheets. When the voltage is applied, a number of electrodes modulate the electric field, which makes the charged toner particles move from the dented electrode pass through the aperture of control electrodes and reach the paper beneath the pulling electrode to generate a toner dot. This research applied the various constant values of the voltage to the electrodes and investigated the toner dot sizes. The model of an electric field is also included.