Some Fundamental Performance Aspects of the Xerox iGen3 Development System

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Abstract

The Xerox iGen3 digital press uses a gapped powder-cloud development system known as Hybrid Scavengeless Development (HSD) for its Image-on-Image process. HSD differs in many ways from typical two-component magnetic brush development systems. This paper describes the iGen3 HSD system and discusses some of its fundamental performance characteristics, concentrating on the relationship between developability and parameters that affect electric fields and toner supply.

Introduction

The Xerox iGen3 is a high speed digital production press that was introduced in 2002. It incorporates many new technologies, as evidenced by over 400 patents specific to the machine. A recent overview of the product highlighted some of the key technical accomplishments. [1] iGen3 assembles the four CMYK color separations on the photoconductor prior to a single transfer, a process known as Image-on-Image (IOI). Central to IOI in iGen3 is a development system capable of high speed and quality without degrading previously developed images. Traditional magnetic brush development is inadequate for high quality IOI because of the physical interaction of the brush with the photoconductor. To satisfy the requirements of IOI for iGen3 a new development system was invented. This paper describes that development system and presents some of its fundamental performance characteristics for solid area development.

HSD Description

iGen3 uses a powder cloud development system known as Hybrid Scavengeless Development (HSD). A simplified schematic of iGen3 HSD is shown in Fig. 1. The housing is located on the side of the photoconductor and thus develops horizontally. A dual auger sump contains two-component developer that is picked up by a magnetic brush roll. Two semiconductive donor rolls are each loaded with a toner layer by the magnetic brush at a loading nip. The toner layer mass is controlled by a dc voltage between the magnetic brush and the donor rolls. The photoconductor is spaced from the donor rolls and moves in the same direction as a donor surface at the interface between the roll and the photoconductor. A set of four thin electrode wires is mounted near each donor surface in the development nip. The wires are biased with an ac voltage, which generates strong oscillating electric fields between the wires and the toned donor surface. These fields break the adhesion of the toner to the donor surface, creating a cloud of toner that can be gently harvested by the latent image fields.

Figure 2 shows a more detailed view of the interface between a donor roll and the photoconductor. The diagram is drawn approximately to scale. The coating of the donor roll is electrically relaxable. Its conductivity and dielectric thickness are chosen to maintain high electric fields between the wires and the roll while avoiding electrical shorting. Time constants for charge movement in iGen3 donor roll coatings are similar to the period of the wire ac voltage, which is more than an order of magnitude shorter than the dwell time in the development nip. Thus, during development to the photoconductor there is little voltage drop across the donor dielectric due to latent image fields or movement of charged toner.

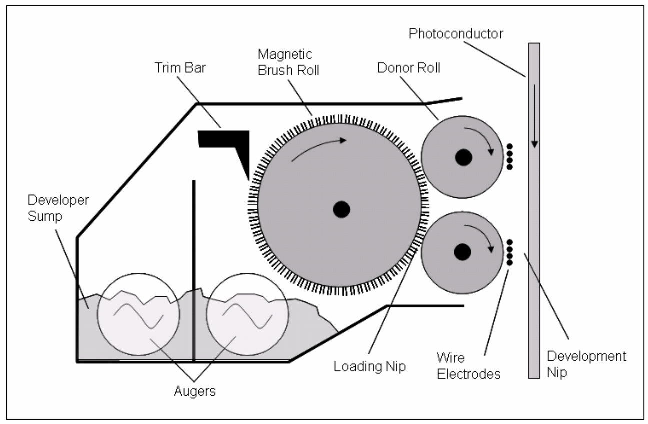

Figure 1. Schematic of an iGen3 Hybrid Scavengeless Development housing.

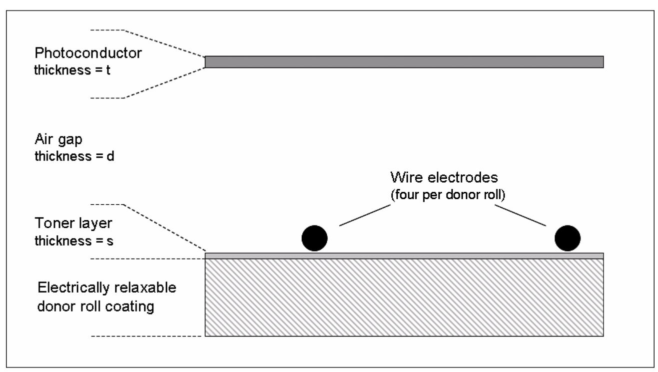

Figure 2. Diagram of an iGen3 development nip.

Standard iGen3 toner [2], consisting of a polymeric resin ground to a nominal size of about 8 μm, was used to generate the data presented in this paper. Unless otherwise specified, the toner charge to mass ratio for the data in this paper was about -40 μ C/g.

Data and Analysis

Development Curves

A typical development curve is shown in Fig. 3, where the toner mass per unit area, M/A, is plotted against the development voltage V_{dev}, which is defined as the difference between the photoconductor surface potential and the magnetic roll dc voltage. The magnetic roll voltage, rather than the donor roll voltage, is used since it roughly equals the potential of the top of the toner layer and is a natural reference for the electric field in the gap.

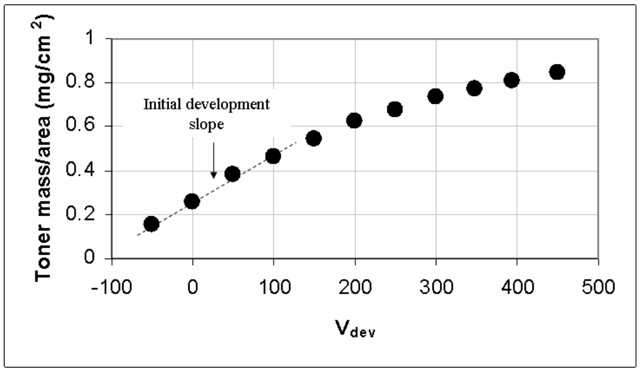

Figure 3. *A typical iGen3 development curve.*

One feature of Fig. 3 that differs from typical magnetic brush development curves is the large offset of the zero-mass intercept from the origin. The wire electrodes recruit toner from the donor roll during the attractive half-cycle of the ac voltage and expel it into the gap during the repelling half-cycle to form the cloud. The charged toner cloud, liberated from its countercharge in the donor coating near the wire, contributes to the electric field in the gap and tends to expand. A development-suppressing voltage difference of about 150 volts is required to prevent the cloud from fully expanding to the surface of the photoconductor and depositing toner.

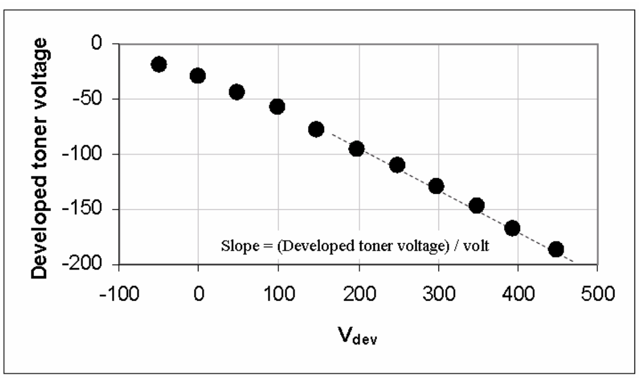

Figure 4. *The toner voltage development curve corresponding to Fig 3.*

The data of Fig. 3 is roughly linear at low toner mass. The slope of this portion of the curve is a useful measure of developability. In some magnetic brush development systems the slope of the development curve decreases at higher mass due to inadequate toner supply. The decreasing slope of the iGen3 development curve of Fig. 3, however, is due to another effect. Figure 4 plots the voltage due to developed toner vs. V_{dev} for the same data as plotted in Fig. 3. The relationship at higher V_{dev} is linear with no indication of saturation. Thus, under a given set of experimental conditions, the HSD system neutralizes a fixed fraction of incremental voltage, or electric field, between the photoconductor and the toned donor surface. The rollover in the toner mass development curve of Fig 3 is not due to insufficient toner supply, but instead reflects the increased effect incremental toner deposition onto a thicker dielectric layer has on the developed image potential. [3] Both the slope of the toner voltage development curve as well as the initial slope of the toner M/A curve will be used as measures of developability in the rest of this paper.

Electric Fields

The electric field in the gap between the donor roll and the photoconductor provides the force to transport toner particles to the latent image. Hays and Feng have proposed a model that relates the rate of mass deposition linearly to the electric field at the photoconductor surface. [4] The charge density of the toner cloud as well as the localized contribution of the wires complicates the calculation of the electric field. However, useful relationships can be drawn between developability and the electric field existing in the gap at the beginning of the development nip, neglecting the contributions of the wires or toner cloud charge. This field, E_0, is given by the voltage difference between the photoconductor and the top of the toner layer, V_{dev}, divided by the total dielectric thickness of the photoconductor, gap, and the donor toner layer

$$E_0 = \frac{V_{dev}}{\kappa_2\left(\frac{t}{\kappa_1} + \frac{d}{\kappa_2} + \frac{s}{\kappa_3}\right)} \tag{1}$$

where t, d, and s are the thicknesses of the photoconductor, the air gap, and the toner layer on the donor roll and κ_1, κ_2, and κ_3 are their respective dielectric constants.

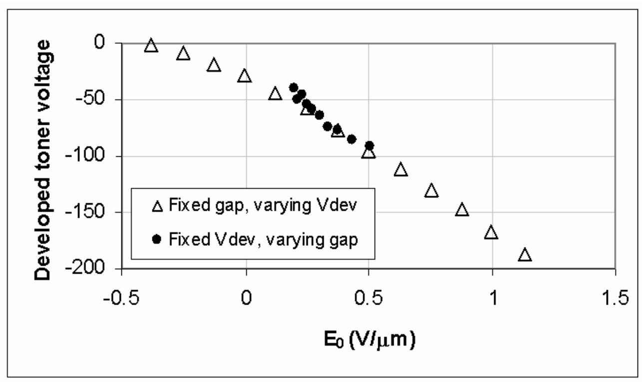

Figure 5. *Toned image voltage as a function of the electric field E_0 for two different methods of varying E_0.*

For a fixed dielectric thickness, changing E_0 by varying the voltage V_{dev} gives the development curve of Fig. 4. According to Eq. 1, an alternative way to vary E_0 is to change the gap d, keeping V_{dev} constant. Figure 5 plots developed toner voltage as a function of E_0, where E_0 was varied either by changing V_{dev} at a fixed gap (the data of Fig. 4) or by changing the gap at a fixed V_{dev} of 150 volts. As E_0 approaches 0, the two curves diverge due to the differing effects of the toner cloud space charge. At the fixed gap the charge density of the toner cloud produces significant development near $E_0=0$. However, achieving the same $E_0 \approx 0$

with gap variation requires a large gap, which diminishes the relative effect of the cloud space charge. Physically, developability must go to zero at infinitely large gap. As one increases E_0 by decreasing the gap, the increase in developability is less than proportional. For example, decreasing the total dielectric thickness by half increases E_0 by a factor of two, yet the total electric field, including space charge effects, increases by less than a factor of two.

In traditional two component magnetic brush development systems, the toner charge to mass ratio, Q/M, has a strong influence on developability. Both insulative and conductive magnetic brush systems are predicted to have M/A inversely proportional to Q/M. [5] The origin of this dependence is an electric field that opposes additional development. In magnetic brush systems this opposing electric field can be due to the charge of the toned image as well as countercharge left in the carrier beads. The higher the Q/M of the toner, the less M/A is required to produce a counter field of a given strength. HSD developability is also proportional to the inverse of Q/M. Figure 6 shows the initial slope of the toner mass development curve plotted against the inverse Q/M of the toner in the magnetic brush. The data are consistent with a straight line passing through the origin. Since the iGen3 donor roll coating transports charge quickly compared to development times, the source of the $(Q/M)^{-1}$ dependence is likely the charge on the toned image rather than countercharge in the donor coating.

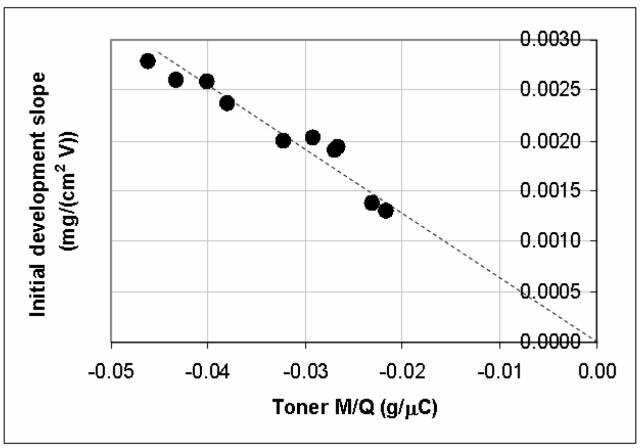

Figure 6. *Developability as a function of the inverse of the toner charge to mass ratio in the magnetic brush.*

Toner Supply and Demand

The parameters discussed so far – latent image voltage, dielectric thickness, and toner Q/M – all affect the electric field responsible for developing toner. Another fundamental factor is the supply of toner. The ac voltage difference between the wires and the donor roll is one of the most important parameters affecting the injection of toner into the cloud. This voltage difference creates the strong localized electric fields necessary to overcome the adhesion of toner to the donor roll. Figure 7 shows the dependence of the slope of the voltage developability curve on the peak-to-peak ac voltage difference between the wires and the donor roll. The onset of development is seen at a threshold of about 300 V_{pp}. This represents the force needed to remove the weakest adhered toners. Developability increases monotonically between 300 V_{pp} and 800 V_{pp}. The dependence of developability on wire voltage can thus be used to probe the distribution of adhesion forces between toners and the donor roll.

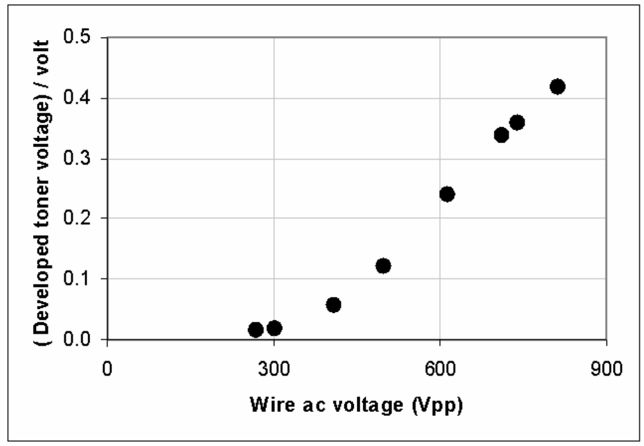

Figure 7. *Developability as a function of the peak-to-peak ac voltage between the wire electrodes and the donor roll.*

Conventional theories of magnetic brush development include the effect of the speed ratio ν between the developing roll and the photoconductor. Mechanisms that contribute to this term include the accumulation of countercharge in the magnetic brush, which decreases the net development electric field, or the supply rate of toner if the image removes a significant fraction of the available toner. Since the HSD donor coating transports charge quickly compared to development times, the effects of countercharge in the coating should be small. Also, the total amount of toner brought to the nip, based on the toner loading of each donor roll and the nominal iGen3 speed ratio ν, is about four times that required by the image. Thus, one might expect that changing the ratio of toner supply to demand by varying ν would have a small effect on developability. Contrary to these considerations, Fig. 8 shows that the developability is roughly proportional to the speed ratio over a range that exceeds a factor of four.

Insight into the dependence of developability on speed ratio is contained in the characteristics of toners that develop. The transfer of toner from the magnetic brush to the donor rolls and then to the photoconductor does not happen with equal probability for all toner sizes. Figure 9 shows the probability distributions for toner mass as a function of toner size from three different locations in the system: the magnetic brush, a toned donor roll, and a solid image on the photoconductor. $P(x)dx$ is the amount of mass with toner diameters between x and $x+dx$, and the integrated donor and magnetic roll distributions are normalized to an arbitrary value of 1. A noteworthy feature of Fig. 9 is that $P(x)$ for the donor roll is shifted significantly toward smaller diameter compared to $P(x)$ for the magnetic brush. This occurs because the donor roll passes multiple times through the magnetic brush loading nip. Complete voltage neutralization of the donor is achieved after only one or two passes. If no toner is removed by the photoconductor, subsequent revolutions of the donor roll do not alter the net toner mass on the donor. Rather, there is exchange of particles between the magnetic brush and the donor. This exchange process leads to size classification, in which the toners that have higher adhesion to the donor surface - likely the smaller ones - tend to remain once they are deposited. The data of Fig. 9 represent the equilibrium state after many passes of the donor through the magnetic brush.

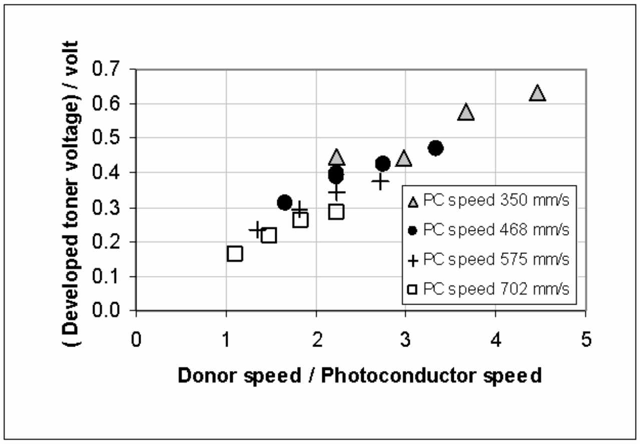

Figure 8. *Developability as a function of the speed ratio between the donor rolls and the photoconductor.*

Development from the donor rolls to the photoconductor allows another chance for selectivity to occur. *P(x)* for the photoconductor in Fig. 9 has been normalized so that its integral is equal to the fraction of total mass removed from the donor rolls by a solid image. One can see that larger particles are more easily developed from the donor rolls. Moreover, virtually every toner greater than about 9 µm on the donor is developed to the photoconductor. Why larger particles develop more efficiently is an interesting question. One possibility is the adhesion distribution for larger particles makes it easier for them to enter the toner cloud. Another possibility is that transport efficiency of particles across a viscous air gap favors larger diameters.

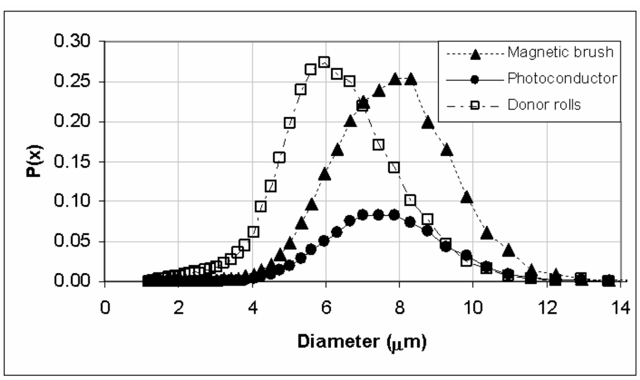

Figure 9. *Toner mass probability distributions as a function of toner diameter. The normalizations are discussed in the text.*

Thus, the development efficiency of toner depends strongly on the diameter. This likely explains why developability is proportional to the speed ratio ν even when there is apparently adequate toner supply. While sufficient total toner is available at lower speed ratios, higher speed ratios either deliver more or require less of the easily developed toner species.

While Fig. 8 shows an approximate proportionality between developability and speed ratio, closer inspection reveals deviations from universal behavior. At a given speed ratio, slower photoconductor speeds have slightly higher developability. A possible explanation for this could be the relationship between donor speed and the time period of the wire ac voltage. In the limit of large donor speed, when a fresh toner layer is brought to the wires on successive ac cycles, developability should become independent of donor speed. At current iGen3 speeds the donor rolls move about two wire diameters between ac cycles. Simulations [6] suggest that a wire will recruit donor toner from a width on the order of its diameter, so perhaps the slight separations seen in Fig. 8 are the precursors to this large donor speed limit. Experiments with single wire development nips and varying ac frequency would help elucidate this area.

Conclusion

In summary, the iGen3 HSD development system is a novel technology for producing high quality color images in an IOI process. Primary factors affecting solid area development are the electric field in the gap and the supply of toner relative to the demand. The preference to develop specific species of toner is also measurable. HSD provides a fertile laboratory for exploring the physics of powder cloud development across a gap.

Acknowledgments

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Author Biography

Mark Hirsch is a principal scientist at Xerox Corporation. He joined the company in 1987 after receiving a Ph.D. in physics from Cornell University. His work has concentrated on development systems, influencing a variety of products such as the Xerox single-pass highlight color printers, magnetic brush systems using Emulsion Aggregation toner, and the iGen3 digital color production press. He holds 14 patents in electrophotography.