

Electrostatic Toner Transfer to an Intermediate: Results from a Continuum Model

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Abstract

Toner transfer to an intermediate web or roller is currently practiced in several commercial electrophotographic color printers. Here, we examine the electrostatics of toner transfer to an intermediate using a one-dimensional continuum model.[1] The model calculates the time evolution of electric fields and ionization currents in and around the transfer nip. Discussed in detail are the effects of nip width, toner stack height, pre-transfer erase, and the resistivity of the intermediate on the electric fields responsible for toner transfer, in addition to the unwanted artifacts resulting from both premature toner transfer and ionization in and around the transfer nip.

Introduction

Electrostatic toner transfer is accomplished in a variety of ways and has been demonstrated in commercial copiers and printers with corotrons, transfer rollers, transfer webs, intermediate rollers, and intermediate webs. Here we examine transfer to a resistive intermediate roller. The motivation behind modeling the electrostatics of transfer is to better understand the intricacies of toner transfer and to provide direction for optimizing the geometry, set points and material properties of elements associated with the transfer process.

While the use of a transfer intermediate involves two transfers, the first from the photoconductor to the intermediate and the second from the intermediate to the print media, here we focus solely on the first transfer. Judicious choice of the properties of the transfer rollers and biasing strategy allows the photoconductor-intermediate (PC-IT) nip to operate independently of the transfer from the intermediate to paper.[2]

The electric field varies spatially in and around the PC-IT transfer nip and is determined by the transfer geometry, applied voltage, process speed, and electrical properties of the photoconductor, toner layer, and intermediate roller. Large fields are necessary to produce efficient transfer of toner, however, both in the transfer nip and in adjacent regions, air breakdown limits the magnitude of the field. If the field reaches the limit of electric field breakdown (known as the Paschen limit[3,4]) in the area just prior to the nip (the pre-nip region) ions of one polarity travel in the air gap along electric field lines to the intermediate. Ions of the opposite polarity travel toward the photoconductor and can reduce the toner charge before the toner reaches the transfer nip. Typically, pre-nip ionization reduces transfer efficiency and can severely degrade image quality because of the non-uniformity of the discharge.

Furthermore, even electric fields below the Paschen limit can cause problems in the pre-nip region. High fields can induce premature transfer of toner to the intermediate. Also called pre-nip transfer, when the toner transfers in the pre-nip region across relatively large air gaps, the sharpness of the image degrades because the toner particles tend to spread as they cross the air gap.

Next, consider the toner in the transfer nip (where the photoconductor contacts the intermediate). Just as in the pre-nip region, ionization in the nip can alter toner charge and degrade transfer efficiency and image quality.

At the nip exit, the toner transfers to the intermediate then enters the post-nip region where the air gap again grows and the Paschen limit decreases. Post-nip ionization can only increase the magnitude of the charge on the transferred toner, thus ionization in the post-nip region is not necessarily detrimental to image quality because the image has already transferred. However, image disruption is possible if the discharge gets too energetic, or if the toner charge gets too large.

To summarize, a few key electrostatic factors need to be co-optimized in the toner transfer process. The electric field in the nip needs to be as large as possible without incurring breakdown in the nip and the field in the pre-nip region needs to be kept as small as possible to reduce pre-nip transfer and prevent pre-nip ionization.

Choosing the appropriate roller resistivity allows for suppression of the pre-nip field while at the same time achieving an appropriate transfer field in the nip. The roller resistivity controls the rate at which the electric field changes in and around the transfer nip.[1,2,5] The transfer model is used here to monitor ionization currents and the electric field in and around the PC-IT transfer nip while factors affecting transfer, such as the toner stack height, the resistivity of the intermediate and PC-IT nip width, are varied.

Theory

The electrostatics of toner transfer to an intermediate can be modeled by solving a boundary value problem similar to the one described by Zaretsky.[1] He showed that the electrostatics of transfer, including ionization could be mathematically described using a one-dimensional continuum model having a time varying capacitance to represent the air gap of a transfer nip. Whereas Zaretsky described transfer from a photoconductor to paper backed by a resistive roller, here transfer from a photoconductor to a resistive intermediate is examined. Figure 1 shows the model system having four homogenous layers: photoconductor, toner, air, and intermediate, where the permittivities of these layers are ε_{PC}, ε_t, ε_o, and ε_{IT}, and the thicknesses of the layers are d_{PC}, d_t, $d_a(t)$, and d_{IT}. The geometry of the nip is accounted for by mathematically describing how the air gap d_a changes with time. Other parameters considered include the resistivity of the intermediate ρ_{IT}, the space charge in the toner layer σ_t, and the initial surface charge on the photoconductor σ_{PC}. By allowing for an initial surface charge on the photoconductor different exposure levels can be modeled along with the effect of pre-transfer erase (near complete erasure of the photoconductor prior to transfer). An applied voltage V, between the electrodes on the photoconductor and intermediate, provides the appropriate transfer field. Other parameters accounted for by the model include the surface speed of the process, the length and width of the transfer nip, the mobility of ions in air, and the packing fraction of the toner layer. The model is one-dimensional, thus, tangential currents and fields are not considered. Following Zaretsky, the equations describing the voltage drop across each layer are:

$$\dot{V}_{IT} = \frac{\dfrac{-V_{IT}}{\rho_{IT} d_{IT}}\left(\dfrac{d_{PC}}{\varepsilon_{PC}} + \dfrac{d_t}{\varepsilon_t} + \dfrac{d_a}{\varepsilon_o}\right) + \left(\dfrac{V_a \varepsilon_o}{\dot{d}_a} - J\right)\dfrac{d_a}{\varepsilon_o}}{\dfrac{\varepsilon_{IT}}{d_{IT}}\left(\dfrac{d_{PC}}{\varepsilon_{PC}} + \dfrac{d_t}{\varepsilon_t} + \dfrac{d_a}{\varepsilon_o} + \dfrac{d_{IT}}{\varepsilon_{IT}}\right)} \tag{1}$$

$$\dot{V}_a = \left(\frac{V_{IT}}{\rho_{IT}\varepsilon_{IT}} - \frac{\left(\dfrac{V_a\varepsilon_o}{\dot{d}_a} - J\right)}{\left(\dfrac{d_{PC}}{\varepsilon_{PC}} + \dfrac{d_t}{\varepsilon_t} + \dfrac{d_{IT}}{\varepsilon_{IT}}\right)} \right) \frac{\dfrac{d_a}{\varepsilon_o}}{\left(\dfrac{d_{PC}}{\varepsilon_{PC}} + \dfrac{d_t}{\varepsilon_t} + \dfrac{d_a}{\varepsilon_o} + \dfrac{d_{IT}}{\varepsilon_{IT}}\right)} \tag{2}$$

$$V_t = \left(\frac{\varepsilon_{PC}}{d_{PC}}\left(V - V_{IT} - V_a\right) - \sigma_{PC} - \frac{d_t \sigma_t}{2}\right) \Big/ \left(\frac{\varepsilon_t}{d_t} + \frac{\varepsilon_{PC}}{d_{PC}}\right) \tag{3}$$

$$V_{PC} = V - V_{IT} - V_a - V_t \tag{4}$$

Dots above the variables indicate a time derivative.

The nonlinear, time-varying, ordinary differential equations, (1) and (2), are solved numerically using an adaptive step size algorithm available in the software Matlab.[6] Air breakdown in the air gap is handled by checking whether the electric field has exceeded the Paschen limit for each step of the iteration. If the field is found to be larger than the limit of air breakdown then the ionization current J needed to reduce the field to the Paschen limit is calculated.

The solution to any given set of parameters can be manipulated to provide most of the important details of the electrostatics of transfer in all regions of the transfer nip. Examined here are the electric fields, both in the toner layer and in the air gap, and when, where, and how much ionization occurs.

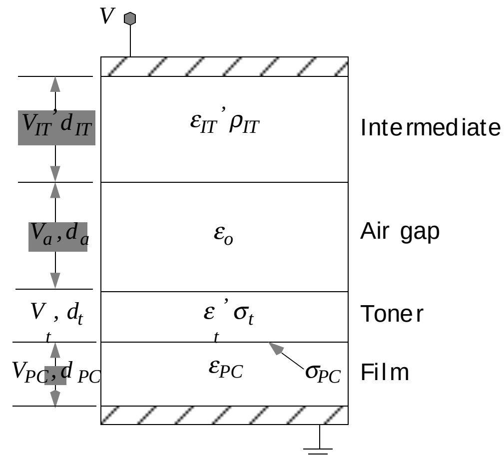

Figure 1. The one-dimensional continuum representation includes the four layers affecting the electrostatics of toner transfer.

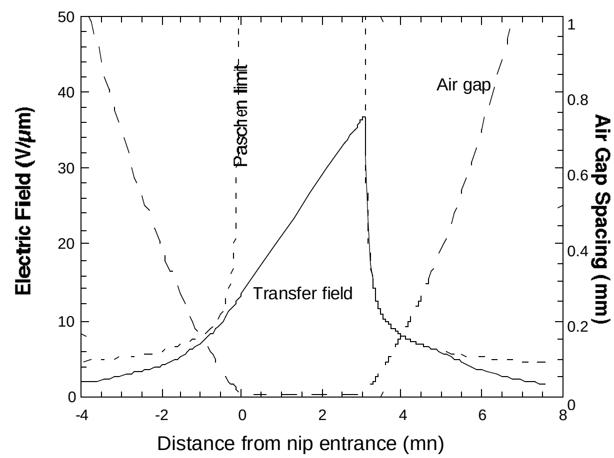

Figure 2. Output from the transfer model depicts the electric field in and around the transfer nip. Also shown are the Paschen limit and the size of the air gap.

Model Results

The model calculates the voltages across each of the layers by considering a single slice of the layered package as it travels through the transfer nip. The electric fields in the layers are calculated in all areas of the nip from the voltage data. Figure 2 shows a typical plot of the electric field in the air gap between the photoconductor and the intermediate in and around the transfer nip. Also shown are the Paschen limit and the size of the air gap. Important features from the transfer profile are the maximum field achieved in the nip and the field achieved in the pre-nip region. For the conditions of Figure 2 the field in the air gap increases slowly in the pre-nip region then nearly monotonically when in the transfer nip and finally, in the post-nip region, the field follows the limit of air breakdown as ionization occurs. This behavior is characteristic of transfer with relatively high resistance intermediates.

The model is first used to examine the impact from the toner stack height on the transfer field and the field in the pre-nip region. Figure 3 plots two different conditions: the solid lines show the relationship when the photoconductor is completely erased prior to transfer and the dashed lines show the relationship when no pre-transfer erase is used. Because the effect on the transfer field from erasing the photoconductor is large, the applied voltage for the two cases had to be adjusted to portray a realistic comparison. In each case, the applied voltage was set to produce a maximum transfer field of 10 V/µm in the nip at the bottom of a 16 µm toner stack. In other words, the electrostatic transfer force on the 16 µm toner stack is the same for both cases.

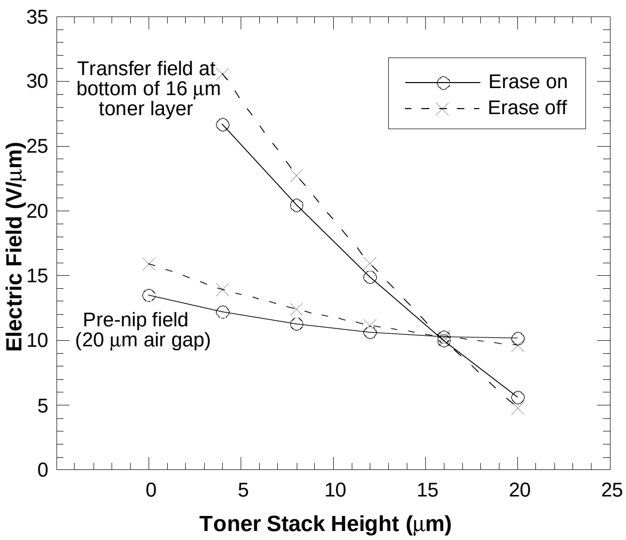

Figure 3. The transfer field and the pre-nip field decrease as the toner stack height increases (ρ_{IT} = 3 x 10^8 Ω-cm).

As the toner stack height increases the transfer field decreases because the toner charge screens the applied electric field. In addition, the increase in the dielectric thickness further reduces the field. Efficient transfer requires a strong electrostatic force, hence small electric fields must be avoided. Unfortunately, if the electric field in the toner stack gets too large then air breakdown occurs. Thus, the flattening of the curve shown in Figure 3 resulting from the erasure of the photoconductor yields some, albeit small, improvement in latitude because the transfer field on large toner stacks can be maintained while reducing the risk of ionization in low density toner stacks.

Also shown in Figure 3 is the electric field in the pre-nip region in the air gap between the toner and the surface of the intermediate. To illustrate the effect on the pre-nip field a somewhat arbitrary position corresponding to a 20 µm air gap was chosen. Here a smaller dependence from the toner stack height is found, and the curves again indicate some improvement in latitude due to erasure of the photoconductor.

To examine the effect from the resistivity of the intermediate, Figure 4 plots the maximum transfer field at the bottom of a 16 µm toner stack as a function of the nip width (the contact width between the photoconductor and the intermediate). In order to examine the sensitivity of the transfer field to nip width for the different resistivities, the applied voltage is adjusted to maintain a field of 10 V/µm at the bottom of the stack for a nominal nip width of 6 mm. The plot shows that the sensitivity to nip width decreases as the resistivity of the intermediate decreases. When the roller resistivity is 1.5 x 10^8 Ω-cm there is almost no change in the transfer field for nip widths 2 mm and greater. Considering this feature alone, a system with such an intermediate allows for considerable design latitude.

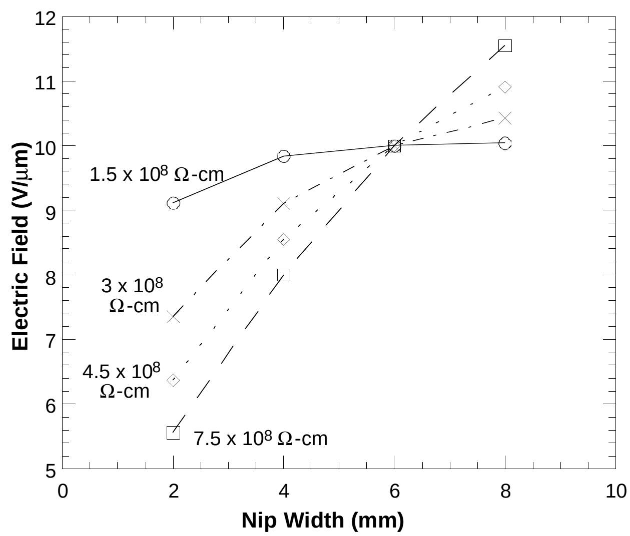

Figure 4. The electric field at the bottom of a 16 µm toner stack plotted as a function of nip width indicates that lowering resistivity decreases sensitivity.

The resistivity of the intermediate also affects the fields in the pre-nip region. To make a realistic comparison, the applied voltage is adjusted so that the maximum transfer field is equal for each value of resistivity. To represent the influence of resistivity on the electric field in the pre-nip region two curves are plotted in Figure 5: the field at the start of the nip and the field at which the air gap between the toner and the intermediate is 20 µm. The pre-nip field begins to level out at around 3 x 10^8 Ω-cm. Low resistance intermediates have larger pre-nip fields because their shorter time constant causes the field to increase at a faster rate. The significant impact found for the pre-nip field may have important implications for image quality. As reviewed above, low pre-nip fields are desirable because large pre-nip fields may reduce image sharpness by causing premature transfer of toner in the pre-nip region.

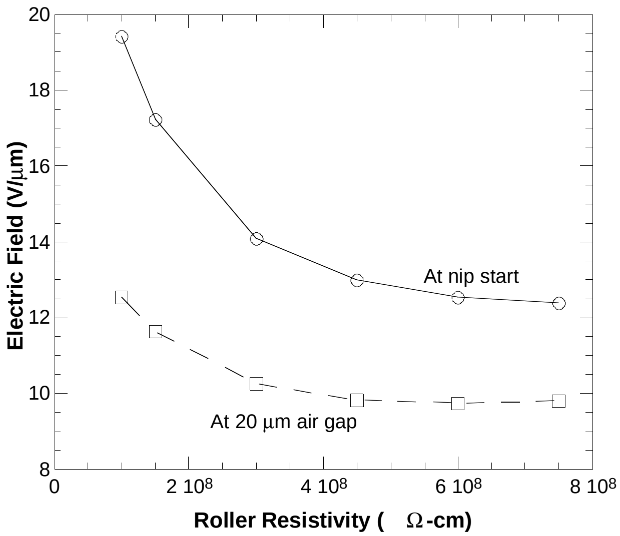

Figure 5. Electric fields in the pre-nip region decrease as the resistivity of the intermediate roller increases.

Conclusion

Electric fields in and around the transfer nip between a photoconductor and a resistive intermediate roller were calculated using a one-dimensional continuum model. Erasure of the photoconductor prior to transfer was shown to improve transfer latitude with respect to toner stack height. Increasing the resistivity of the intermediate roller was shown to increase sensitivity to nip width variations but decrease the fields in the pre-nip region.

References

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Biography

Thomas N. Tombs received his Ph.D. (1992), M.S. (1989), and B.S. (1987) degrees in electrical engineering from the University of Rochester. At the University his research focused on particle electrostatics and electromechanics. In 1987 and 1988 he investigated xerographic magnetic brush technology at Xerox. Since 1992 he has been at Eastman Kodak Company performing research and development in the area of electrophotography. Dr. Tombs holds 16 US patents and has published articles on particle electrostatics and electrophotography.

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