

Dynamic Electrical Conductance Profiles of Liquid Electrophotographic Inks and Corona Devices

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Abstract

Spatial, cross-sectional, electrical conductance profiles of the ink (toner) "nip" and charging corona "nips" are measured as a function of position and electric field for purposes of programming into a dynamic analog electronic circuit model of an emerging, high quality liquid electrophotographic process. The circuit model itself, and its performance, are presented in a separate paper[1]. The space charge states for various experimental liquid inks will be discussed, along with the particular transport parameters. Detailed calculated transient current flow, photoreceptor surface voltage rise, and resulting image deposition for a tiny unit area of photoreceptor traversing the development nip (within the development nip itself), will be discussed for various experimental process situations.
Experimental, field dependent, spatial conductance profiles for the involved corona charging devices will include scorotrons and corotrons, specially designed for the process.

Introduction

The high quality liquid electrophotographic process modelled herein, and designed as a computer color printer, is shown schematically in Figure 1. The photoreceptor is charged, exposed to a scanning laser, and developed with a liquid ink

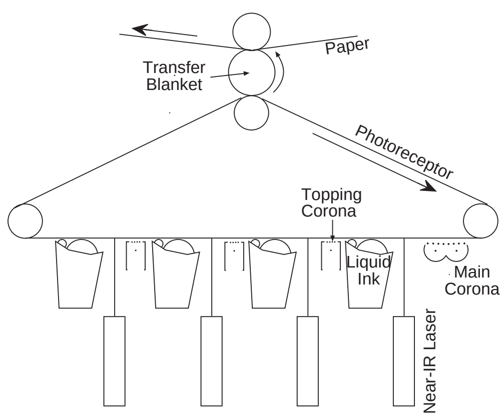

Figure 1. Diagram of Printing Process

which is substantially "film-formed" after the development station. It is rapidly and sequentially recharged, exposed, and developed with at least 3 more color liquid ink stations before the film-formed and dried composite color image is transferred *en masse* to an intermediate transfer blanket, from which the image is again transferred to the final paper or transparency receptor. It is the focus of the present paper to measure experimentally the detailed electrical conductance "profiles" of the liquid ink (toner) applied between the developer rollers and the photoreceptor surface, as well as the corona device profiles. These spatial and electric field dependent electrical characteristics will then be used in the dynamic electronic circuit model of the development process presented in the following companion paper[1].

Figure 2 is a representation of the liquid ink "nip" region between the developer roller and the photoreceptor surface.

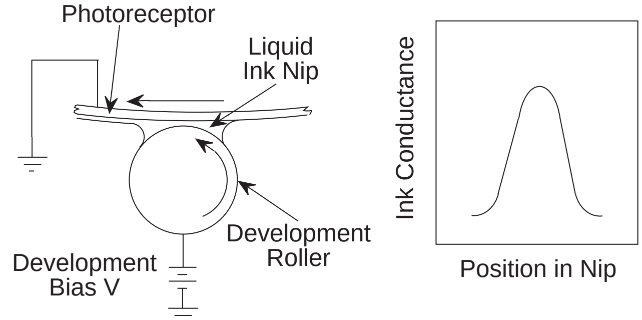

Figure 2. Liquid Ink Nip and Conductance Profile

Since the process utilizes discharged-area-development, which is common for printers, the developer roller is biased to a development potential which is less than the photoreceptor surface potential of the unexposed background areas, but considerably more than the residual potential of the exposed image areas of the photoreceptor. The developer nip width is only a fraction of an inch, and any particular tiny unit area of photoreceptor traverses it in approximately 100 milliseconds. Since all of the "interesting" development current transient and ink deposition occurs in this small nip region, it is important to the process physics to accurately measure and model the dynamic electrical characteristics within the nip region itself.

Experimental Setup

To electrically "probe" the liquid ink nip dynamically, a narrow, 0.8mm "stripe" electrode is "scanned" through the ink nip[2] as depicted in Figure 3. Two "guard" electrodes are disposed on each side of the electrically isolated stripe electrode. The development roller is biased to various "test" voltages while the stripe electrode and the guard electrodes are biased to the same potential (ground in this example). The development current sampled by the isolated stripe electrode as it is scanned through the development nip is recorded, giving a

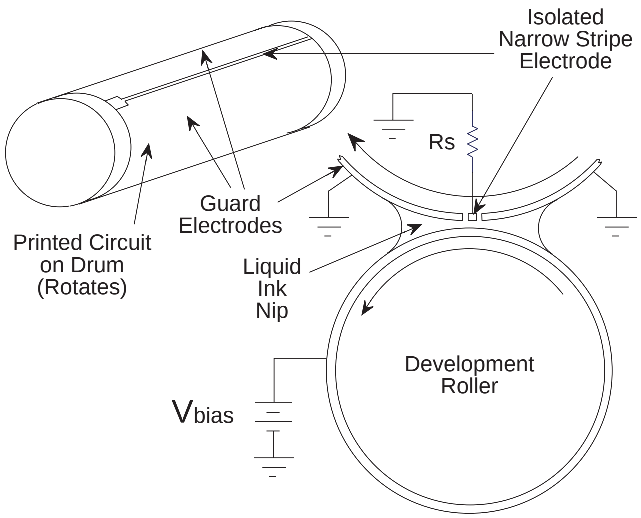

Figure 3. Experimental Arrangement to "Probe" Ink Nip

characteristic "bell" shaped profile. Typically, the guard electrodes are biased to the same potential as the stripe electrode so the electric field in the nip is not distorted, and the current in the stripe electrode circuit is recorded separately to achieve a "high resolution" current profile. As a check, the current integral through the profile is compared to the total nip current as measured by the large guard electrodes.

One can, alternatively, bias the guard electrodes to different potentials from the stripe electrode for special-case measurements, such as "cross-talk" currents through the ink between adjacent electrode elements which are at different potentials. These simulate transient cross-talk currents through the ink (as between differing potential areas of the photoreceptor, as they enter the ink nip such as from an unexposed background area at a high potential to an exposed image area at a low potential).

Figure 4 is a set of ink (toner) current profiles for a particular black ink at a concentration typical of that used in the printer. The different curves represent different development roller surface speeds, and therefore different rates of transport

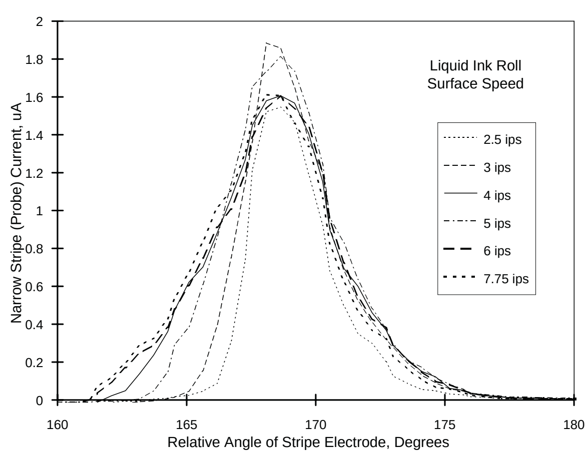

Figure 4. Ink Current Profiles. Test Voltage=100 volts.

of ink into the nip, from speeds below the photoreceptor surface speed, to speeds above. These profiles are all at one particular, constant test voltage, 100 volts. While the higher transport rates result in a slightly wider nip, as one might expect, the maximum current is roughly constant. Since the peak currents are essentially the same, one can conclude that, for these test parameters, the development currents are independent of the ink transport rate, i.e. there are more-than-sufficient current carriers at all the transport rates for the particular applied test voltage. Since there are more mobile charge carriers available for conduction <u>between</u> the electrodes than the charge <u>on</u> the electrodes for the voltage applied, one can describe this condition as "space charge limited," and only an increase in the applied test voltage results in an increase in conduction current.

To fully characterize the electrical conditions in the nip, one must measure similar profiles at other applied electrode voltages. These are shown in Figure 5, where the test voltages were varied from 100 volts to 500 volts for the same ink as in Figure 4. These measurements are repeated for the full color ink set.

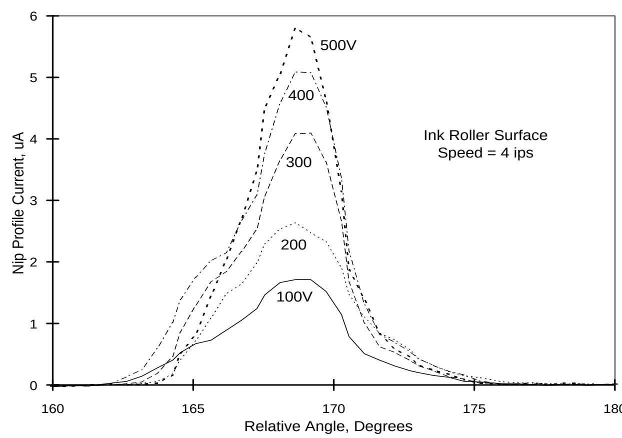

Figure 5. Ink Current Profile Voltage Dependence

Out of interest, a somewhat "depleted" ink was characterized in like manner. This was a low concentration ink after long use in the printer after it normally would have been replenished or replaced. It no longer resulted in "target" optical density development. Its current profiles for various ink transport rates are shown in Figure 6, where a test voltage of 500 volts was used (5 times that for Figure 4). In this case the current profiles changed dramatically with ink transport rate, indicating there were fewer mobile charge carriers <u>between</u> the electrodes than charge <u>on</u> the electrodes. In electronic parlance, this is known as the "emission limited" case, or simply, "non-space-charge-limited." We'll return to this later.

These spatially dependent and electric field dependent current profiles are then converted into conductance profiles, which turn out to be somewhat electrically field dependent themselves, as well as spatially dependent. The conductance profiles can be used to calculate the development current in the actual development nip, millisecond by millisecond. Keep

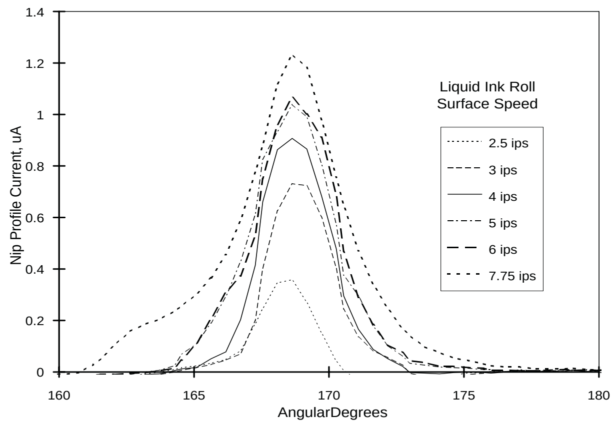

Figure 6.Ink Current Profiles for Almost Depleted Ink. Test Voltage=500 volts.

in mind that the experimental profiles described above were generated between conductive test electrodes that were held at a constant voltage throughout the nip scan. In the actual case of a photoreceptor traversing the development nip, a tiny elemental image area of photoreceptor enters the nip at $V_{residual}$, and rapidly charges-up to $V_{development}$ at some time in the nip, cutting off the development current as it does, assuming the development goes to "completion." From the experimental position-dependent and field-dependent conductance data, one can "track" the tiny element of photoreceptor through the development nip millisecond by millisecond, compensating for the locally-changing electric field as the developing photoreceptor traverses the nip, charging toward the development voltage as it does.

Figure 7 shows this calculated elemental area development current density ($\mu A/cm^2$) for a tiny image area traversing the nip with the black ink discussed earlier. The current profile for the scanning stripe electrode is also shown to identify the physical center of the nip. It is clear that the development proceeds rapidly to completion by mid-nip, as evidenced by the cutting-off of the development current and the rise in

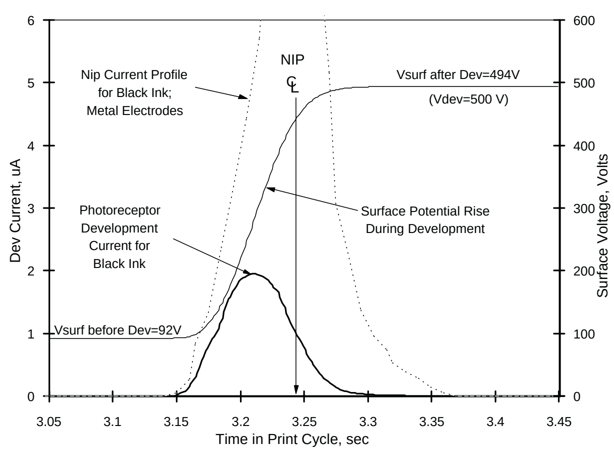

Figure 7. Calculated Elemental Development Current for Photoreceptor.

surface potential to the development bias of 500 volts by mid-nip. The current integral (area under the development current curve) for this case corresponds to a developed optical density of about 1.6 to 1.7.

By contrast, Figure 8 shows the development current transient for the somewhat-depleted toner discussed above. It is

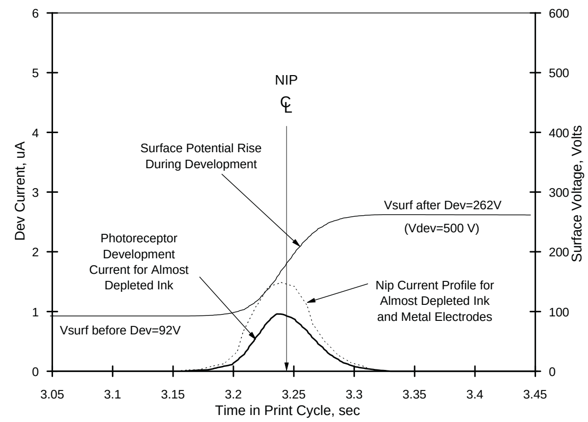

Figure 8. Calculated Elemental Photoreceptor Development Current for Almost Depleted Ink.

plotted at the same scale as Figure 7 for comparison. Again, the scanning stripe electrode current profile is shown to identify the center of the nip. In this case, the development never goes to completion as evidenced by the small development current integral and the fact that the photoreceptor surface potential never rises to the development voltage. The photoreceptor current rises and falls "in phase" with the conductance profile, never delivering sufficient current integral for development completion or to reach the target optical density.

These conductance profiles and development current integrals in the nip are used in the dynamic electronic circuit model presented in the following companion paper.

Corona Charging Devices

The same scanning stripe electrode apparatus is used to generate corona charging device profiles, again, for the purpose of calculating the detailed rise in photoreceptor surface potential within the corona "nip." These profiles are also used in the electronic circuit model in the following companion paper. Figure 9 shows the current profile for a two-wire scorotron device under one set of conditions. The individual grid wires are apparent in the profile. A whole family of profiles are measured at various plate voltages, scorotron screen voltages, and corona currents (the total current flowing from the corona wire, usually held constant).

Figure 10 shows the profiles for a small specially-designed corona charging device which must be both narrow physically and have a well-defined "sharp cutoff" at its edges in the "process direction." It is termed a "topping corona," since its purpose is to recharge a photoreceptor from its post-development potential of about 400 or 500 volts up to its normal initial potential of about 600 volts. The sharp cutoff requirements are due to not wanting any spurious corona "overspray" into the development region on the "upstream" side, or into the

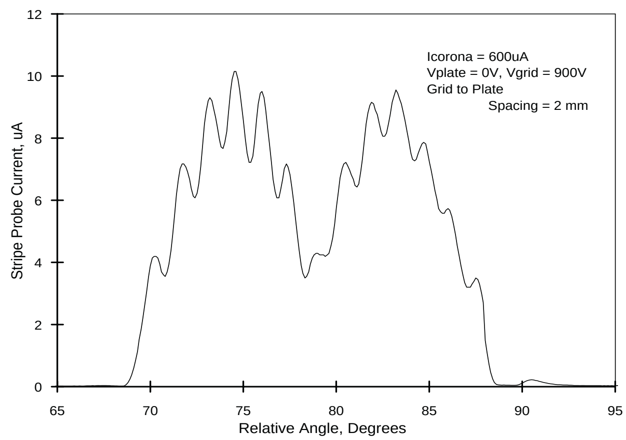

Figure 9. Current Profile for a Two-Wire Scorotron (Main Charging Corona).

laser exposure region on the downstream side. The different "plate voltages" are the applied voltages on the stripe electrode and the guard electrodes, with respect to ground.

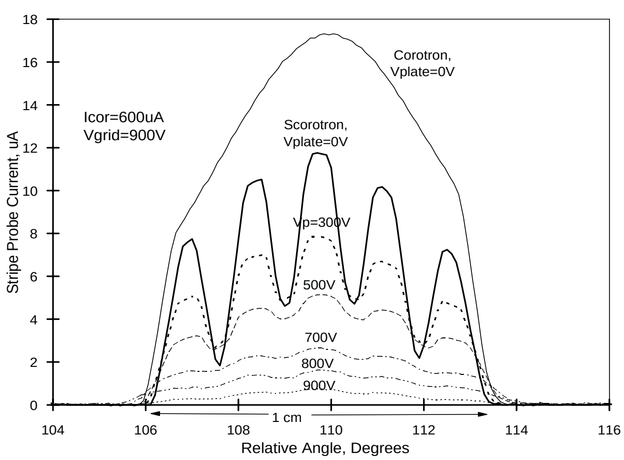

Figure 10. Current Profiles for "Topping Corona."

While the topping corona is normally used with a screen grid as a scorotron device, its performance without the grid wires, as a corotron is included. It is clear from the curves how relatively inefficient the scorotron embodiment is, despite its better surface voltage control. The current integral through the profile (total corona current delivered to the external plate) can be plotted as a function of the plate voltage as in Figure 11, to show the "control characteristics" of the device; i.e. how well it controls the photoreceptor surface potential as it rises to the desired final value and the corona device ceases to deliver charge to the plate. Here, one sees the value of the grid-controlled scorotron device over the corotron, despite the former's low current efficiency. The plate current drops to zero for the scorotron, as the plate voltage (photoreceptor) reaches its "control voltage," independent of its initial voltage. This is particularly desirable if different areas of the photoreceptor require different current densities to recharge

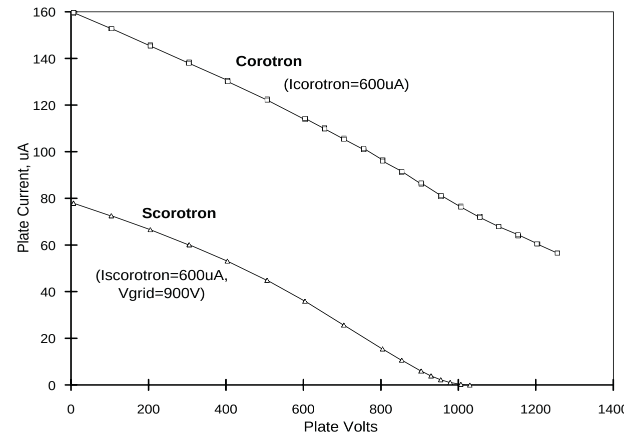

Figure 11. "Control Characteristics" of the Topping Corona as a Scototron and a Corotron

to a given surface voltage. The control voltage is, of course, a function of the grid voltage, corona current, etc.

These current profiles, intrinsically and strongly electric field dependent, are converted to conductance profiles, which still have a small amount of field dependence. These can be dealt with much more easily in numeric integration calculations, and in the electronic circuit model for which these measurements were undertaken.

Conclusion

Spatial, cross-sectional, electrical conductance profiles of the ink (toner) nip and charging corona nips are measured as a function of position and electric field for purposes of calculating the actual time-dependent current flow to a photoreceptor within the development nip and within the corona charging nip, regions normally inaccessible to measurement devices. The profiles are further used for programming into a dynamic analog electronic circuit model of a high quality liquid electrophotographic process.

References

1. Arthur R. Kotz and David A. Ender, Paper I-060, NIP 14, (1998).
2. Similar to: R. M. Schaffert, *Electrophotography*, John Wiley & Sons, New York, 1975, p. 466.

Biography

David Ender received his B.S. in Physics from Bucknell University and Ph.D. in Physics at Montana State University in 1982. After teaching at Norwich University, he joined 3M's Corporate Technology Lab where he jointly led their research group in nonlinear optical materials resulting in design, fabrication and characterization of novel electro-optic modulators and new $\chi^{(3)}$ materials. In 1992, he joined 3M's IS&T Sector Lab to lead their effort in characterization and physics of organic photoconductors. In 1996, the laboratory was transferred into 3M's spin-off company, Imation, where he is currently a Senior Research Specialist. He is a member of the APS and the OSA, and has several publications, 2 issued patents and 3 pending.