Single Pixel Development in a New Electrographic Printing System

G. Bartscher,*,▲ F. Morgenweck,▲ K.-U. Preissig, and D. Rohde,▲
NexPress, Kiel, Germany

S. O. Cormier, D. Kostyk and R. Lyness
NexPress USA, Rochester, New York

G. Hauptmann
Heidelberg Printing Machines, Heidelberg, Germany

L. B. Schein✦
Independent Consultant, San Jose, California

In order to improve the quality of text and graphic printers, companies have increased the resolution of the imaging subsystem and decreased the diameter of toner particles in electrophotographic powder marking technologies. We have been developing a new electrographic printing technology in which the latent image is formed by contacting a write head with many metal fingers to square metal pads on 50 μm centers (500 dpi) fabricated on an insulating cylinder. This system has demonstrated the ability to print for the first time, to our knowledge, in any powder marking system, both black and white single pixels at 500 dpi, using normal 9 μm diameter toner. A theoretical explanation for this result is given.

Journal of Imaging Science and Technology 45: 523–528 (2001)

Introduction

Electrophotography is a well-known and widely used technology for printing. The most commonly used implementation of electrophotographic printers uses a laser or an LED bar as an illumination source and develops the latent image with dry toner. Despite the wide usage of this technology, there are, however, some drawbacks with respect to image quality. For example, color consistency of electrophotographic printers has not reached the standard set by offset lithography or gravure printing. One of the important contributors to the lack of color consistency in electrophotographic printers is the low or inferior quality of the single pixels. To the knowledge of the authors, it is not possible to print single white pixels and single black pixels in one image in electrophotography with dry toners. A single pixel is the smallest dot that the printer can address. In first order, the pixel size is defined by the spot size of the laser or the spot of a single LED of the LED bar.

Original manuscript received October 10, 2000

▲ IS&T Member

✦ IS&T Fellow

* to whom correspondence should be addressed

Previously presented at IS&T's NIP15: International Conference on Digital Printing Technologies, October 17-22, 1999, Orlando, Florida, USA.

Images created with electrophotographic printers typically use digital halftoning to create different gray scales.[1] Full color images are produced by superimposing for example 4 colors (black, cyan, magenta, and yellow) on paper. Obviously, a more consistent gray scale for a single color will result in an improved total color consistency. In digital halftoning typically squares of several pixels (for example a 4×4 array) are organized to form a superpixel (of 16 pixels). Within this superpixel a number between zero and all pixels can be either white or black, resulting in $n + 1$ gray levels, if n is the number of pixels in the superpixel. Electrophotographic systems use digital halftoning because this method produces more consistent gray scales than analog halftoning, where the gray level of single pixels is controlled by exposure level. The electrophotographic process is most stable for printing "white" (= zero density) and "black" (= full density), while intermediate states (for example half density) are less stable.[1] Digital halftoning avoids intermediate levels and therefore increases gray scale consistency.

The ability to produce single pixels in electrophotography depends on four of the subsystems, expose, develop, transfer and fuse. Throughout the years much attention has been given to the effect of the development subsystem on single pixel development, focusing on the role of the toner diameter. It has clearly been shown that the use of small diameter toner particles leads to better defined single pixels.[2–5] By using toner particles as small as one micron, as practiced in liquid development systems, off-

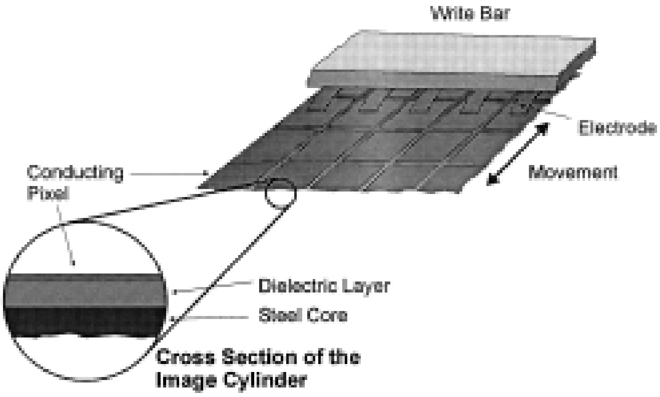

Figure 1. Principle scheme of contact electrography.

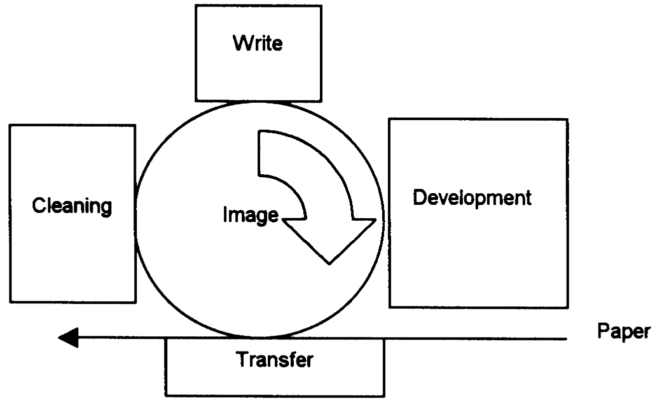

Figure 2. Schematic diagram of the experimental set-up for contact electrography.

set quality images have been produced,[6] but with the associated system challenges of liquid development.[1] The effect of electrostatic transfer has been identified and quantified[3]: as the paper leaves the transfer nip, Paschen breakdown scatters the toner particles causing degraded edges and single pixels. The effect of fusing is smaller.[3] The subsystem with the largest effect on single pixel development is the imaging system. It is for this reason that the light spot size has been decreased through the years. However, laser scanners and LED bars produce approximately Gaussian light beams, whose diameter must be adjusted to make both single black pixels and solid areas. Making the diameter large enough to create uniform solid areas precludes the possibility of making good single white pixels. Indeed, to our knowledge, no known electrophotographic system can produce both single black and white pixels in the same image.

In this article we present a new printing technology called contact electrography, which offers improved quality while still using dry toner. Experimental results that demonstrate improved single pixel development will be discussed. The theoretical reasons for the improved single pixel development are outlined (a more detailed discussion of this issue is presented in a different study.[7])

Contact Electrography—A New Imaging Process

The new imaging process called contact electrography is based on the very defined charging of micro-capacitors located on the surface of an image cylinder using solid sliding contacts. The simplified schematic drawing in Fig. 1 shows a write bar carrying an array of microscopically small contact springs on an insulating substrate that are physically contacting the image cylinder surface, which is patterned with conductive pads that are electrically isolated from each other. In the cross section portion of Fig. 1 the composition of the image cylinder surface layers is indicated. The conductive core of the image cylinder is coated with a dielectric layer of 8 µm thickness, which is again covered with a wear-resistant and conductive coating that is structured into square pads. The pads together with the dielectric and the conductive core of the image cylinder create the above-mentioned micro-capacitors. By rotating the image cylinder underneath the sliding contacts and applying different voltages to the finger electrodes, every single pad can be charged with high precision to a desired potential within an extremely short time. This feature allows nearly perfect control over the pad potential, which is related via the electric field to the optical density of the corresponding pixel after development. Due to the conductive nature of the pads (thereby acting as equipotential planes) an additional inherent feature of this technology is the perfectly constant spatial distribution of the potential at the pad surface within the dimensions of the pad.

These are basic differences in comparison to other electrographic or electrophotographic imaging processes using a dielectric surface or a photoconducting surface. With those technologies it is rather difficult to achieve and control precisely and reproducibly:

1. the desired surface potentials for the different pixels,
2. an even potential distribution within the pixel,
3. a good confinement of the pixel.

These difficulties result from the facts that in conventional electrography electrons and/or ions have to be deposited on an insulator and for electrophotography a radiation source with a non-square intensity distribution is used to discharge the photoconductor. Intuitively it seems reasonable that these drawbacks of electrophotography will result in an improved image quality for contact electrography. This is in fact observed and will be discussed below.

Experimental Setup

The experiments were done with a pitch of 50 µm for the electrode array on the write bar and the same dimensions for the corresponding pad structure on the image cylinder. The image cylinder is covered with full square shaped pads of 40 µm × 40 µm area size and 10 µm space, building columns and rows (a planar pattern with 4-fold symmetry, see Fig. 1).

For testing the image quality of contact electrography prints, a commercially available nonmagnetic monocomponent gap development system was used. The distance between development roller surface and image cylinder surface was 250 µm with +125 V DC bias applied to the development roller. Additionally, an AC sine wave of 1500 V_{pp} at 1000 Hz was applied. The average size of the ground toner particles used was around 9 µm.

The image developed on the image cylinder was either analyzed under the microscope or transferred to paper by using electrostatic transfer. After transfer the image cylinder surface was preconditioned for the next revolution by means of a cleaning device and charging/discharging devices. All tests were run at an image cyl-

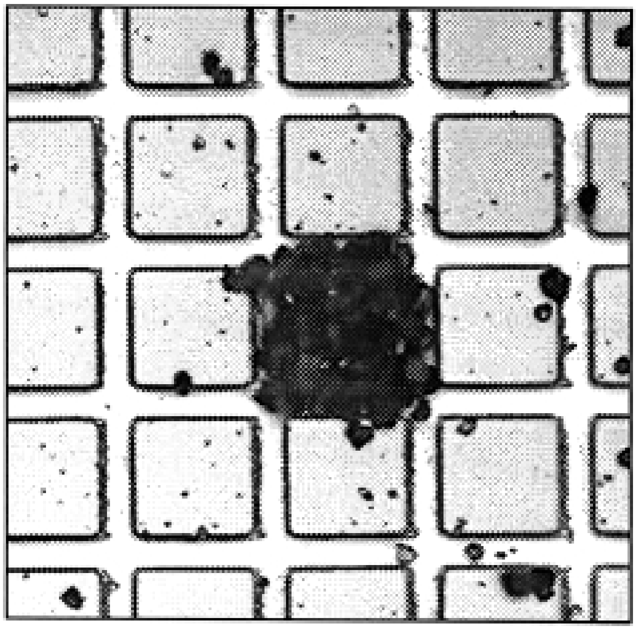

Figure 3. Single black pixel at 500 dpi on the surface of the image cylinder. Some toner extends over the area of the conducting pixel so that it has a size of about 65 to 70 μm.

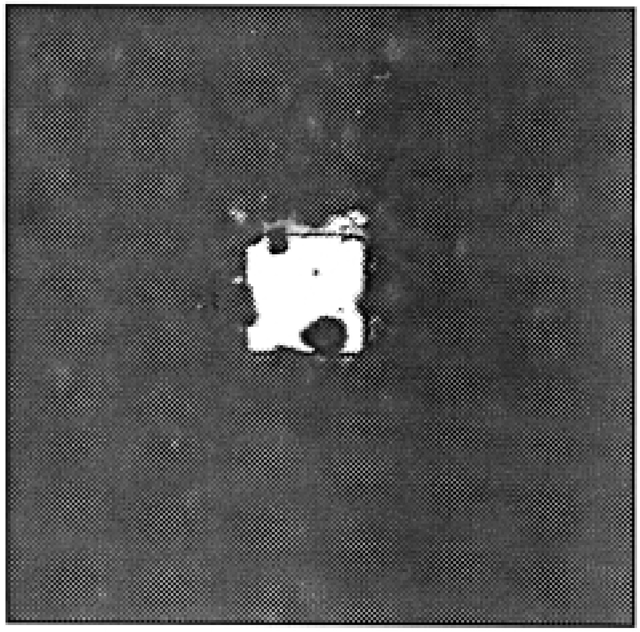

Figure 4. Single white pixel at 500 dpi. The white area has a size of about 40 μm.

inder surface speed of 4 cm/s, although the process is inherently capable of much higher speed. A schematic diagram of the experimental set-up is given in Fig. 2.

Results and Discussion

In this section we will present results from printing with contact electrography. These results are discussed especially with respect to the impact on image quality.

Single Pixels

Single dark pixels are created when all of the writing elements are driven by a pattern consisting of continuous 0 V with a short pulse to 250 V sent to one element while the image cylinder passes. Single white pixels use continuous 250 V with a short pulse to 0 V sent to one element.

Figure 3 shows a single dark pixel on the image cylinder. Dark pixels appear as 65 to 70 μm squares, with toner sitting not only on the conducting area of the charged pixel, but also covering most of the gap to adjacent pixels. As shown in Fig. 4, single white pixels appear as 40 μm untoned squares in a full density field on the image cylinder. Most of the image cylinder pixel edges are still visible, with the toned field covering the dielectric between the pixels of the image cylinder. Note that the single black pixels and the single white pixels were obtained in the same experiment without optimizing the development system parameters separately for each image.

The difference in size between white and black pixels can be explained by a finite conductivity of the surface of the dielectric between pixels. Some of the charge leaks from the highly conducting pixel to the dielectric and thus increases the size of the developed area.

What has been demonstrated here with contact electrography, namely single white pixels in a black area as well as single black pixels in a white area under identical conditions, is something that, to our knowledge, has not been possible with electrophotography. On a high level the rational for this result is that contact electrography has a much better latent image due to the metal pixels on the surface of the image cylinders. This is confirmed by calculations of the electric fields for both technologies under similar configurations. More details are discussed in the next section "Electric Fields".

The ability to print single white and black pixels has two important benefits for image quality:

1. **Consistent Color:** The fact that contact electrography can print single black and single white pixels under standard conditions and that this is not possible with electrophotography shows, that basically dots can be printed with a higher stability when using contact electrography. "Stable" means that shape and even more important size are more consistent than in electrophotography. As discussed in the introduction, this is very important for consistent color of gray scale reproduction.
2. **High Density Areas:** In images that are made by digital halftoning the high density areas are printed by laying down full density and just leaving a very low number of pixels within a given area white. Obviously, the smallest element that can be left white, is one pixel in contact electrography. For electrophotography, more than one pixel has to be kept white, so that a dark area contains bigger white spots, which can be captured by the eye and thus negatively affect image quality.

Some clarity of the images on the image cylinder is lost during transfer and fusing. However, enough of the difference compared to electrophotography is maintained on the receiver substrate to result in image quality advantages for contact electrography.

Adjacent Pixels

In electrophotography intermediate gray levels are made by partially exposing pixels (by controlling the on-time of the laser or LED) next to fully developed pixels.

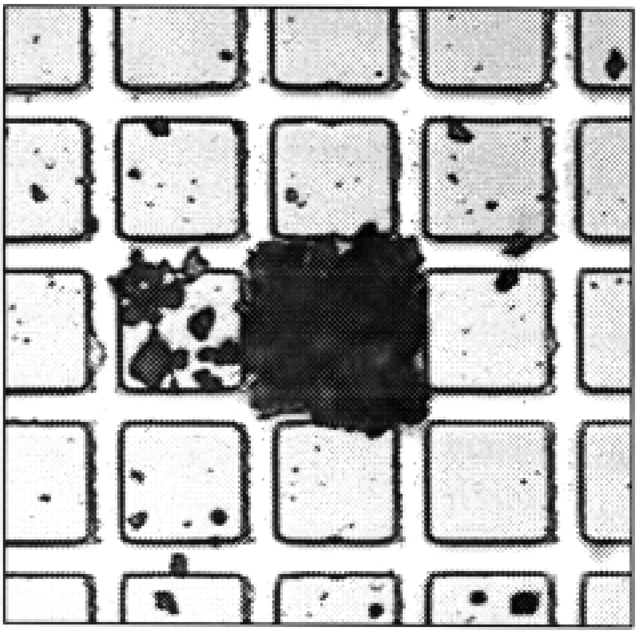

Figure 5. A black pixel (right, 120 V) directly beside a gray pixel (left, 30 V) on the of the image cylinder. Size and shape of the black pixel are, in first order, independent from the gray scale of the neighboring pixels.

The question of how contact electrography behaves in this respect is the subject of the following discussion.

Several print runs were made while printing two directly neighboring pixels at different voltage levels. In one configuration, the first of the two adjacent pixels was a 120 V pixel, The second pixel was at lower voltage, 30 V. Figure 5 shows a typical result: the full voltage (120 V) pixel has a full density toner stack, while the lower voltage pixel (30 V) has a partial toner stack. The toner on the high voltage pixel creates a toned square covering the pixel and the dielectric between pixels of the image cylinder. This is typical of the single pixels printed in earlier experiments (as described above). The toner on the lower voltage pixel remains mostly on the conducting pixel of the image cylinder, with much of the pixel material remaining visible. This pixel has a low density, and has been seen to have toner scattered across the entire conducting pixel area, with no clear preference to be at the side near the high voltage pixel.

Tests at higher voltage levels (for example 250 V for the black and 125 V for the gray pixel) showed at first sight two black pixels on the image cylinder. A closer investigation showed much more toner on the black pixel, where the stack height was about 20 μm, where by contrast it was only about 10 μm on the gray pixel.

Clearly in contrast to electrophotography, contact electrography does not show a change in pixel width as a function of the gray level of adjacent pixels. Though contact electrography does not offer the opportunity to vary line width, this is compensated by the possibility to print individual gray pixels.

Low Angle Lines

One of the characteristics of contact electrography could in principal limit image quality: the pixel structure could be visible in the printed image, especially with narrow lines (as for example 200 μm) and a shallow angle to one of the pixel symmetry axes.

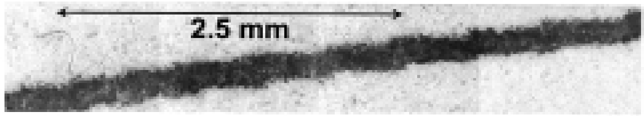

Figure 6. A 250 μm wide line printed with contact electrography on paper after electrostatic transfer and hot plate fusing. The steps of the 50 μm squares are not visible to the human eye under normal viewing conditions.

Narrow lines were printed on paper using the described configuration of contact electrography to examine the effect of pixel steps on the edges. The lines are 200 μm to 250 μm wide and 5° to 10° inclined to the process direction. This angle range was deliberately chosen because steps are much more visible to the human eye at these shallow angles than at steeper angles, as for example 45°.

The low angle line was observed on the image cylinder, and showed the expected steps. The toner completely filled the charged pixels, with fully untoned pixels beside the line as observed in all of the preceding tests. The steps in the image are exactly as would be expected for an image made of these pixels. The appearance of the low angle lines electrostatically transferred to paper is shown as a photomicrograph in Fig. 6. It shows a 3.175 mm section of the line. The visual appearance of these 0.25 mm wide lines is quite uniform. The corners of the 50 μm squares have lost some sharpness due to transfer and fusing so that they are not visible to the human eye under normal observation conditions. However, as seen in Fig. 6, the steps are there and under extreme close observation also visible to the human eye. In the case of better transfer and fusing conditions the sharpness of the steps in the printed image could increase and become visible to the human eye. In this case higher resolution (smaller pixels) or printing single gray pixels in between the steps can be used to obtain a straight appearance of the line edges to the human eye.

In a different set of experiments, even narrower lines of 50, 100, and 150 μm were printed and fused on paper. Here, steps were visible on paper under normal observation conditions. A closer investigation revealed that the eye did not really see the rounded 50 μm edges, but the transition between 50 and 100 μm width. This fact is not considered as a meaningful drawback for image quality for contact electrography, because printing applications with lines of a width of less than 200 μm are extremely rare. If such narrow lines are desired, the use of gray levels on the adjacent pixel in the corner of the steps (as mentioned before) offers an opportunity to improve the appearance of the lines at the expense of a sharp transition from high-density line to white background.

In summary, the results obtained so far do not indicate any problems for image quality due to the square pixel shape.

Electric Fields

As shown and discussed above, contact electrography can print single white and single black pixels under identical conditions. By a theoretical analysis we found that the reason for the differences between the two technologies is a result of the different electric fields. In this section we will give an outline of the analysis. More details will be offered in a further study.[7]

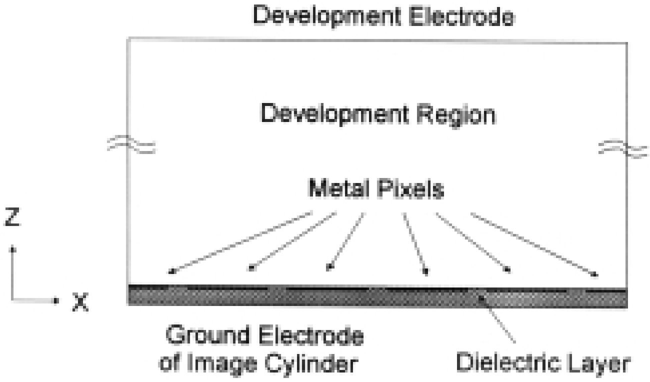

Figure 7. Geometry for field calculations for contact electrography. The dielectric layer has a thickness of 8 μm and a relative dielectric constant of 3. The distance between the image cylinder surface and development electrode is 250 μm, while the relative dielectric constant of this region is 1.

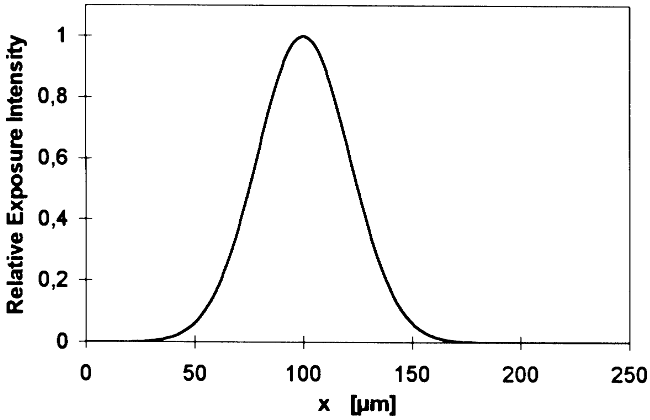

Figure 8. Exposure intensity profile for a single black line with the center at x = 100 μm.

A two-dimensional model has been created to calculate the electric fields for single black and single white pixels for contact electrography as well as electrophotography. Using only 2 instead of 3 dimensions significantly simplifies the calculations, while the main results also hold for 3 dimensions.[7] A different way of interpreting the results is that lines rather than pixels are modeled.

Figure 7 shows the geometry of the model for contact electrography. The model uses the parameters of the experiments. 40 μm conducting pixels with 10 μm gaps (corresponding to a pitch of about 500 dpi), dielectric layer with a thickness of 8 μm and a relative dielectric constant of 3, and 250 μm distance between the surface of the image cylinder and the development electrode, held at a potential of +125 V.

The potential of the pixels is varied between 0 and + 250 V, depending of the printed pattern. The AC voltage in the development system is ignored in the model because its function it to free the toner that the DC voltage collects.[1]

A similar model is used for electrophotography. Here the thickness of the dielectric layer is 20 μm (a typical value for an organic photoconductor) with a relative dielectric constant of 3. Exposure is modeled with a Gaussian beam profile as shown in Fig. 8, with a pitch P = 50 μm (equivalent to about 500 dpi) for neighboring channels. The size of a dot D (defined as the diameter where the intensity has dropped to $1/e^2$) has been chosen as 1.7 times the pitch. This is a value typically used in laser and LED printers to give good solid areas. In this model, the photoconductor is charged to –600 V. Dark decay is neglected and for simplification a linear discharge curve is used, which results in a potential of –100 V for a maximum exposure. The development electrode is at a DC bias of –450 V.

The models and the parameters were used as input for a finite element program[8] to calculate the electric fields. Figure 9 shows the resulting field for a single black line for contact electrography and electrophotography. Note that it is a line rather than a single pixel because of the 2 dimensional nature of the model. Figure 10 shows the situation for single white lines. In both figures, the electric field is plotted at a height of z = 4 μm above the surface of the image cylinder or photoconductor. This position has been chosen because it samples in first order the field at the center of the first monolayer of a layer of toner particles sitting on a developed surface. Following the approach of Allen and co-workers,[9] we assume that a negatively charged toner particle will deposit and thus contribute to forming a visible dot, in areas, where the normal component of the electric field E is greater than zero, while particles will be drawn away from areas with E < 0.

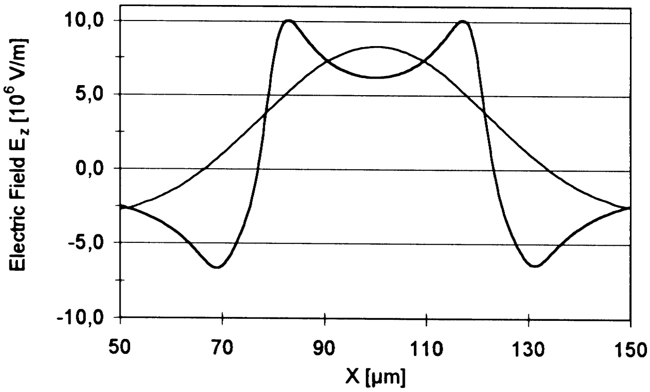

Figure 9. Normal component of the electric field for the conditions for printing a single black line (centered at x = 100 μm) of the model for contact electrography at z = 4 μm (thick line) and electrophotography (thin line).

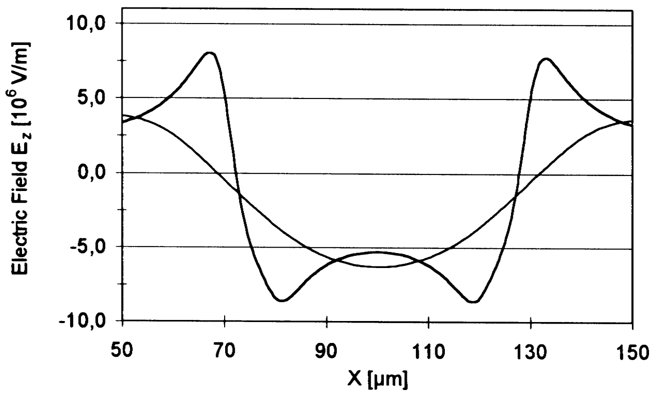

Figure 10. Normal component of the electric field for the conditions for printing a single white line (centered at x = 100 μm) of the model for contact electrography at z = 4 μm (thick line) and electrophotography (thin line).

Figures 9 and 10 clearly show the better defined electric field for contact electrography compared to electrophotography. For electrophotography, the width of a single black line is 68 μm (at $z = 4$ μm), which is considerably more than the nominal width of 50 μm defined by the pitch of 500 dpi. Similarly, the white line is with 63 μm (at $z = 4$ μm) too large. For contact electrography, however, the width of the black line with 46 μm and the white line with 55 μm (both at $z = 4$ μm) are much closer to the pitch of 50 μm. The difference in the electric fields explains the observed better development with contact electrography.

The reason for the improved field with contact electrography is shown in a detailed analysis in Ref. 7. The conducting areas of the pixels confine the charges to the pixel areas, giving a very defined border between charged and uncharged areas, which result in an electric field closer to the ideal rectangular shape. In electrophotography, the initially uniform charge layer is structured by an exposure device with a Gaussian-like beam profile, leading to smoother transitions between charged and uncharged areas.

Summary and Conclusions

Superior image quality of contact electrography compared to electrophotography has been experimentally demonstrated on a pixel level. At the present resolution of 500 dpi single white pixels in a black area as well as single black pixels in a white area have been printed under identical conditions. This is something that, to our knowledge, has not been possible with electrophotography. The reason for the improved performance with contact electrography is the better-defined electric field due to the confinement of the surface charges to the area of the conducting pixels. In electrophotography the Gaussian beam profile does not allow for such a well-defined spatial surface charge distribution.

An improvement of the quality of single pixels leads to an improvement of image quality, especially with respect to color consistency.

References

1. L. B. Schein, *Electrophotography and Development Physics,* Laplacian Press, San Jose, CA, 1992.
2. R. J. Gruber and E. N. Dalal, *Seventh Toner and Development Industry Conference*, Imaging Materials Seminar Series, Diamond Research Corp., Santa Barbara, CA 1990.
3. L. B. Schein and G. Beardsley, *J. Imaging Sci. and Technol.* **37,** 451 (1993).
4. S. Chiba and S. Inoue, *Advance Printing of Paper Summaries, Fourth International Congress on Advances in Non-Impact Printing Technologies,* SPSE, Springfied, VA, 1988, p. 105.
5. K. Shigehiro, K. Arai, Y. Machida, T. Fukuhara, Y. Hirose, and K. Takiguchi, *Ninth International Congress on Advances in Non-Impact Printing Technologies*, IS&T, Springfield, VA 1993, p. 93.
6. B. Landa, *SPIE,* **5,** 2171 (1994).
7. To be published: G. Bartscher, S. Cormier, B. Lyness, L. B. Schein, Comparison of the Electric Fields of Electrophotography and Contact Electrography, *J.Electrostatics.*
8. Quickfield© by Tera Analysis, 1993–1995; www.tera-analysis.com
9. J. B. Allen and A. B. S. Coit, Comparison of the Single Pixel Development of DMD (Digital Micromirror Device) and Laser Exposure Modules in Electrophotographic Printing, *J. Imaging Sci. Technol.* **43**, 309 (1999).