Electrostatic Defect Mapping of Xerographic Photoreceptors with a Capacitive Probe

Zoran Popovic, Steven Dejak, Philip Waldron, Johann Junginger, and John Graham
Xerox Research Centre of Canada
Mississauga, Ontario, Canada

Satchidanand Mishra
Xerox Corporation
Webster, New York

Abstract

We have recently developed a non-contact technique capable of detecting microscopic variations in the surface potential of charged dielectric films such as xerographic photoreceptors. The technique is based on measuring the charge induced on a small capacitive probe held at a constant distance from a charged sample surface. Distance control is achieved by aerodynamic floating, which is an inexpensive and simple passive feedback system capable of maintaining a constant probe-sample separation despite minor variations in sample morphology. We have used the technique to detect the presence of microscopic electrostatic defects in organic photoreceptors, such as charge deficient spots (CDSs), which are a source of image degradation in xerographic copiers and printers.

Introduction

The quality of a xerographically produced image is strongly dependent on the electrical characteristics of the photoreceptor. One of the first steps of the xerographic process is the charging of the photoreceptor surface to a uniform potential. A high quality photoreceptor will uniformly charge and maintain this uniform surface potential until exposed to light.[1] Unfortunately, many photoreceptors are incapable of uniformly charging on both a macroscopic and microscopic level. These non-uniformities may lead to image defects in the resulting print.

One type of microscopic electrical defect present in many photoreceptors is a charge deficient spot (CDS). A CDS is a localized area, typically ~50 to 150 microns in diameter, which discharges without being exposed to light. Depending upon the development system of the xerographic machine, a CDS will manifest itself as either a small white spot or a small black spot in the resulting print.[2] In the discharge area development (DAD) mode, commonly used by digital copiers and laser printers, a CDS will print as an easily perceived black spot. The presence of a large number of charge deficient spots can severely reduce image quality.

Historically, CDSs were detected by making a print and examining the quality of the final image (i.e. counting the number of black spots). This is a time consuming process, and requires fabrication of a complete photoreceptor for instillation in a xerographic machine. Several stylus or probe based techniques have been developed to detect CDSs.[3-6] While these techniques are capable of reliably detecting CDS, they require lengthy acquisition times. The necessity to scan large areas with high resolution is one of the most difficult technical challenges to recording charge deficient spots. CDS are microscopic defects, and are typically randomly distributed throughout a print. In a standard 8.5”x11” page there may only be 100 printable CDSs; this corresponds to approximately 1 CDS per square inch. Therefore, in order to record a representative image of a photoreceptor, it is often necessary to scan an area as large as 100 cm^2 with < 0.05 mm resolution. There are some commercially available scanning probe techniques, such as a Scanning Kelvin Probe, that are designed to detect changes in surface potential.[7] However, these systems are not designed to scan such large areas and detect changes in surface potential on the order of hundreds of volts.

Recently, a non-contact scanner, based on a capacitive probe, was developed by Z. Popovic et al.[8] This non-contact scanner is capable of detecting the presence of microscopic electrostatic defects, such as CDSs, with a remarkable improvement in scanning speed. However, as this technique is based on recording the charge induced on a small capacitive probe as it scans over the sample, it introduces the stringent requirement of constant probe/sample separation. While this requirement can be achieved by accurate machining of the components or an active feedback system, these solutions are not robust and are very costly. In this paper we will describe a non-contact capacitive probe capable of high resolution defect mapping of dielectric films, in which the probe-sample distance is controlled by aerodynamic floating.[9] The probe can be reproducibly positioned and is insensitive to variations in operating parameters. The passive nature of the feedback system removes the need for expensive active control equipment.

The scanner we developed is capable of recording images at scanning velocities of 50 cm/sec with ~ 37 micron step size.

Instrumentation and Experimental Details

The CDS Scanner

In an experiment the sample, either a photoreceptor drum or a flexible photoreceptor belt wrapped around a drum is rotated with a surface speed of approximately 50 cm/sec (for our drum diameter this corresponds to 60 rpm). As the drum rotates, the photoreceptor is charged to a constant surface potential, typically around –800 V, by the charging device. In our experimental set-up the charging device is a scorotron.[1] The CDS probe is located 120^o from the charging device, corresponding to a ~333 ms delay between charging and the measurement. The probe itself is constructed by embedding an insulated enamel wire, with a diameter of about 100 µm to 200 µm, into a metal casing (shield). A more detailed description of the CDS probe will be given in the next section.

As the photoreceptor moves under the probe, the opto-coupled charge amplifier and data acquisition system will detect and record any changes in the surface potential. The charge sensitive amplifier stage is opto-coupled to another amplifier stage with a gain of ~20. The opto-coupled stage is necessary for two reasons; first it protects the data acquisition from any unwanted spikes due to dielectric breakdown in the experiment, and secondly it allows the user to apply a high voltage bias to the probe (including shield). If the photoreceptor surface is charged to –800V and the probe is at 0V, dielectric breakdown of the air gap is almost inevitable.[10] By applying a bias potential to the probe, that is equal to the average potential on the photoreceptor surface, the voltage gradient will be reduced to zero and dielectric breakdown of the air gap will be prevented. An electrostatic voltmeter (TREK model 368) is used to measure the average potential on the photoreceptor surface. The output of the electrostatic voltmeter (ESV) probe is fed into a TREK 609A high voltage power supply, which in turn applies a bias equal to the photoreceptor potential to the probe. The spatial resolution of the ESV probe is large enough that it will not sense microscopic defects, such as a CDSs, and thus the bias will not be affected by their presence under the probe.

It should be noted that because of the current detection scheme the CDS scanner is only sensitive to changes in surface potential and not absolute values. However, this is not a problem for CDS detection, as the drop in surface potential associated with a CDS is dramatic. It is possible to modify the scanner to record the absolute potential, however this will most likely increase both the time for an experiment and the noise (drift).

A stepper motor is used to move the probe horizontally over the photoreceptor during the scanning process. The drum rotation is defined as the fast scan axis, while the horizontal movement is the slow scan axis. This permits three-dimensional imaging of the sample, with contrast based on local variations in surface potential. An encoder is used to monitor the angular position of the drum thereby ensuring accurate positioning. A light source, located 120^o after the CDS probe, is used to remove ("erase") the potential on the photoreceptor surface. Therefore, in every drum rotation the photoreceptor is both charged and completely discharged, analogous to the operation of xerographic machines.

The Probe

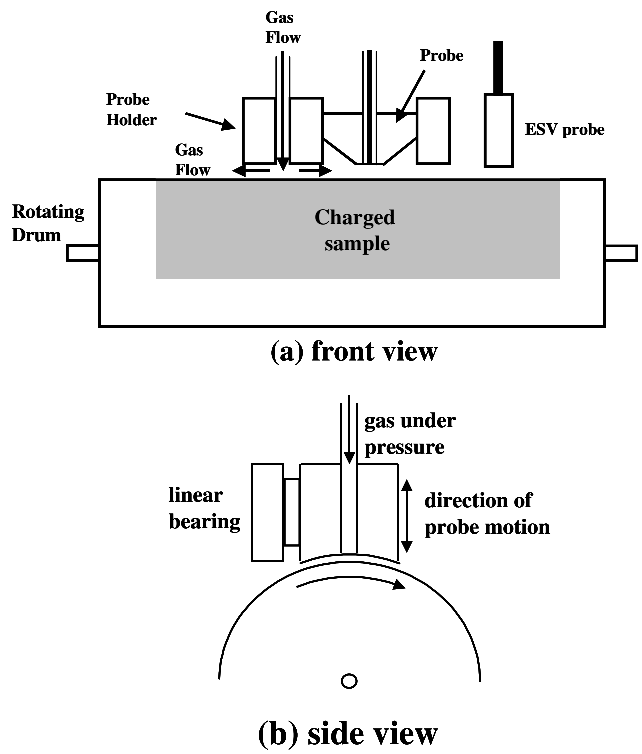

Figure 1. a) A schematic of the probe mounted in the probe holder. Also visible in the figure is the small circular channel, which is used to feed the pressurized gas into the gap between the photoreceptor surface and the probe holder. b) A side view of the probe holder. The probe holder is mounted to a linear bearing and polished to conform to the drum surface.

A schematic of the CDS probe scanning over a photoreceptor is shown in Figure 1. As previously mentioned the probe is comprised of an insulated wire with a diameter of about 100 µm to 200 µm embedded into a metal casing which serves as an electrostatic shield. The metal casing is a low melting temperature metal (alloy of bismuth, tin, lead and cadmium), which is poured into a mould containing an enamel insulated wire and a bare wire providing electrical contact to the shield. Once cooled, the probe is removed from the mould and mounted into a polishing jig. Using emery cloth and diamond paste, the tip is polished to a high finish and the edges of the probe are slightly rounded. The probe tip must be polished until the insulated wire and the metal casing are at the same level.

The combination of the probe, specifically the insulated wire, and the photoreceptor surface, form a small parallel plate capacitor. For a 100 µm wire, at a distance of 60 µm from the photoreceptor surface, the capacitance is approximately 1 fF. The voltage across this capacitor will be 1000V if 1pC (Q=CV) of charge is detected on the tip. Our CDS scanner is capable of reliably detecting changes as small as of 1V or 1fC.

Since charge induced on the probe is inversely proportional to probe-sample distance, it is essential that the distance be kept constant during scanning. Any change in probe-sample distance will be indistinguishable from changes in surface potential. Changes in the probe-sample distance can be reduced with accurate machining of the mounting drum and drum bearings or by employing an active distance control system. Unfortunately, both of these solutions are complicated and costly. We needed a method of reproducibly positioning the probe that is both cost effective and robust. Several methods of positioning the probe were considered, with a passive feedback system based on aerodynamic floating yielding the most desirable results.

Probe-Sample Distance Control by Aerodynamic Floating

A more comprehensive discussion concerning the technical details of aerodynamic floating and its implementation in the CDS scanner has been previously published.[11] To avoid duplication, in this paper we will only present a condensed version of the technical details of aerodynamic floating. Figure 1 depicts the final implementation of the aerodynamic control system. As can be observed in the figure, the probe is mounted into a rectangular holder, which also possesses a small circular channel (1 mm in diameter) running parallel to probe. This channel allows the user to feed a pressurised gas into the gap between the probe holder and the photoreceptor surface. Motion of the probe and holder is restricted to the direction normal to the surface of the photoreceptor by employing a linear bearing. The ESV probe is also mounted onto the rectangular holder. The lower surface of the holder and the probe tip are polished to conform to the surface of the drum.

When a pressurised gas is fed through the circular opening, it escapes with a high velocity to the surrounding atmosphere. The resulting drop in pressure, due to the Bernoulli effect, leads to an attractive force between the probe and the photoreceptor surface. The probe is pulled towards sample until the attractive forces and repulsive boundary layer forces are balanced and an equilibrium position is established. Figure 2 is a graph illustrating the ability of aerodynamic floating to maintain a constant probe-sample separation. The top curve in the graph was recorded without aerodynamic floating and shows a variation in probe-sample separation of over 40 µm as the drum rotates. This variation is a result of a small amount of eccentricity present in the mounting drum. A variation of 40 µm at an average probe-sample separation of only 90 µm, leads to a large and unacceptable error (± 30%). The curve recorded using aerodynamic floating, on the same mounting drum, clearly exhibits significantly less variation in probe-sample separation. Aerodynamic floating has successfully maintained the probe at a separation of ~ 57 µm ± 3 µm, despite the eccentricity present in the mounting drum.

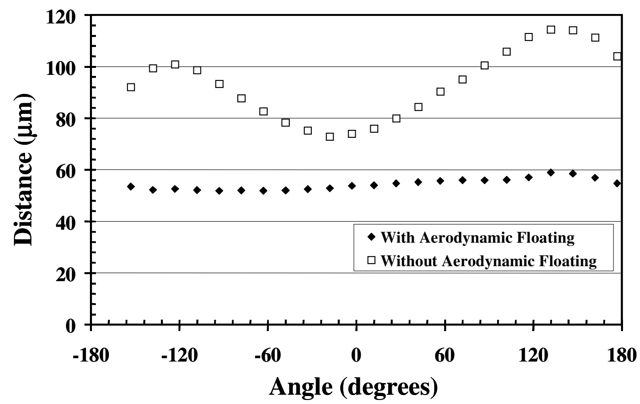

Figure 2. Equilibrium distance vs. angle (drum rotation) graph containing data recorded with and without aerodynamic floating. The equilibrium distance fluctuates significantly without aerodynamic floating, due to the eccentricity of the drum. With aerodynamic floating, the equilibrium position is very stable.

Aerodynamic floating is a cost effective solution for distance control, as the only expense is pressurized gas and there are no expensive feedback electronics or sophisticated mechanical components needed to maintain a constant probe-sample separation. It is also relatively immune to changes in operating parameters, such as probe mass and gas pressure,[11] thereby ensuring reproducibility between scanners operating under slightly different conditions. Interestingly, the probe-sample separation in aerodynamic floating is governed by mean free path of the pressurized gas with the equilibrium position of the probe possessing a linear relationship with the square root of the mean free path of the gas.

Examples of CDS Images

Figure 3 is an example of an image, 28.5 mm x 9.5 mm with 37 µm pixel size, recorded of an organic photoreceptor, where image contrast is a function of surface potential. It took ~ 10 min to record this image. The sample was charged to a surface potential of -800 V at a drum rotation of 60 rpm. Many electrostatic defects (CDSs) are visible in the image as small black areas. Once again a CDS represents a localized region incapable of maintaining charge. It is clear from Figure 3, that the scanner is capable of reliably recording microscopic electrostatic defects such as CDSs.

As mentioned in the introduction, a CDS may manifest itself as an unwanted dark spot on the final print. We have correlated CDSs present in a print with those recorded with the CDS scanner. Figure 4a represents a scan of an organic photoreceptor recorded with the CDS scanner. Figure 4b represents a print test from the same region of the organic photoreceptor in Figure 4a. As can be observed from the figures, the vast majority of the defects visible in the print test were also detected by the CDS scanner (the defects present in both images are circled). It turns out some of the electrostatic defects detected by the CDS scanner are not in the final print. The CDS scanner will detect all the electrostatic defects, some of which may not be printable. Interestingly, the defects present in the print and not in the CDS scanner images do not repeat themselves from print to print. They are random noise in the development system and not a defect on the photoreceptor.

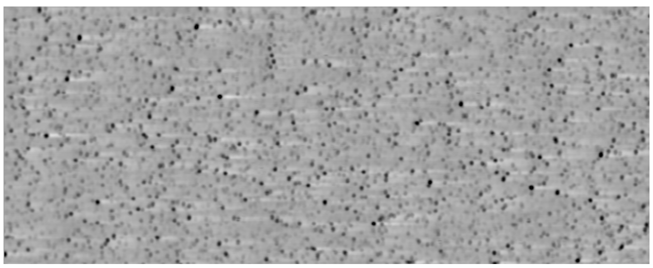

Figure 3. A CDS scanner image, 28.5 mm x 9.5 mm with 37 μm pixel size, recorded from an organic photoreceptor, where image contrast is a function of surface potential. Many CDS are clearly visible in the image as small dark spots.

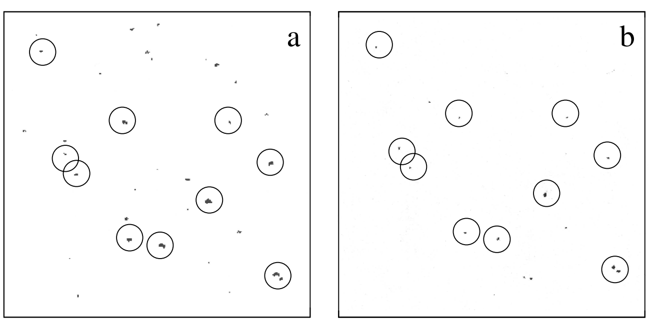

Figure 4. Figure 4a is a CDS scanner image of an organic photoreceptor. Figure 4b represents a print test from the same region of the organic photoreceptor as Figure 4a. As can be observed from the figures, the vast majority of the defects visible in the print test were also detected by the CDS scanner (the defects present in both images are circled).

Conclusions

We have successfully implemented a technique capable of detecting microscopic variations in the surface potential of charged dielectric films, such as organic photoreceptors used in xerography. The technique relies on measuring the charge induced on a small capacitive probe held at a constant distance from a charged photoreceptor surface. The technique has been used to detect the presence of microscopic electrostatic defects in organic photoreceptors, such as charge deficient spots (CDS), which are responsible for image degradation in xerographically produced images.

Acknowledgements

The technical assistance of Samy Mesbah and Gaetano Lavigne is gratefully acknowledged.

References

1. P. Borsenberger and D. Weiss, *Organic Photoreceptors for Xerography*, Marcel Dekker, New York, 1998.
2. L.B. Shein, *Electrophotography and Development Physics*, Springer Verlag, Berlin, 1988.
3. R. Gerhard-Multhaupt and W. Pery, *J. Phys. E* **16**, 421 (1983).
4. S. Singh and G. Hearn, *J. Electrostatics* **16**, 353 (1985).
5. E. Yarmchuck and G. Keefe, *J. Appl. Phys* **66**, 5435 (1989)
6. Z. Popovic, P. Iglesias and D. Parco, *J. Imaging Tech.* **17**, 71 (1991).
7. M. Nonnenmacher, M. O'Boyle and H. Wickramasinghe, *Appl. Phys. Lett.* **58**, 2921 (1991).
8. Z. Popovic, S. Dejak and S. Mishra, *Contactless System for Detecting Microdefects on Electrophotographic Members*, US patent No. 6008653.
9. Z. Popovic and P. Waldron, *Constant Distance Contactless Device*, US Patent No. 6119536.
10. R. Schaffert, *Electrophotography*, Focal Press Limited, London, 1975.
11. Z. Popovic, J. Junginger, P. Waldron and J. Graham, *Rev. Sci. Instrum.* **72**, 3576 (2001).

Biography

Zoran Popovic received his Ph.D. degree in Materials Science from McMaster University, Hamilton, Ontario, Canada in 1974. In the same year, he joined Xerox Research Centre of Canada where he presently holds a position of Research Fellow. Dr. Popovic's main research interest is in photoelectronic properties of organic materials, particularly as they relate to xerographic technology and organic electronic and electroluminescent devices.