An Innovative Quality Mapping Technology for Photoreceptors

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Abstract

Two factors critical to print quality in electrophotography are coating uniformity and coating defects on the photoreceptor. In photoreceptor design, coating materials must therefore be optimized, and methods must be employed to ensure that the photoconductive coating is both free of defects and highly uniform in thickness and electrophotographic properties. A family of computerized photoconductor test systems now commercially available provides an innovative electrostatic mapping method for evaluating uniformity and defects. The systems combine conventional measurements such as charge acceptance and photosensitivity with the ability to detect and locate coating defects as small as 100 µm or less. Key to the success of the mapping method used is a measurement principle closely resembling the basic electrophotographic process. Strong correlations have been demonstrated between test results from these systems and the quality of prints from the photoreceptors tested. In this paper, the design methodology, operational characteristics, system performance, and practical applications of these systems are discussed.

Importance of mapping

Photoconductor mapping in quality measurement reveals coating uniformity — a great advantage, since inconsistencies in either the thickness or the photoelectric properties of the coating will affect print quality. As the demand for color printing increases, the need for detailed uniformity analyses of photoconductors becomes ever more acute.

Mapping likewise reveals coating defects (pinholes, scratches, contamination, etc.), which also result in print defects. Besides exposing defects, mapping provides information for defect characterization.

Further, mapping can be used to evaluate reliability, another important property of photoconductors. As photoconductors gain more widespread use in higher speed printers and digital presses, their physical wear behavior becomes increasingly important.

Mapping technology for photoreceptors

In pursuing significant improvements in photoconductor mapping methodologies for R&D and production applications, a substantial history of effort must be considered, though the results have been mixed. Scanning electron microscopy[1], for example, offers the benefit of high resolution, but is impractical for production use, major drawbacks being its inability to simulate the printing process and the fact that its operation requires a vacuum. Capacitive-coupled shielded probes have also been used[2-8], but have generally suffered from low signal-to-noise ratios, and, like SEM systems, do not simulate printer operation. Popovic[9] has offered a variation of the shielded probe technique, but it involves contamination of the photoconductor surface. Toner image methods[10-11] also affect the photoconductor surface, and interpretation of results is complicated by uncontrolled variables introduced by the development system. Atomic force microscopy[12-13] offers high resolution, but its practicality is limited, especially since, like the other systems mentioned, it does not simulate printer operation. Finally, the impressive ability of the human eye to detect and characterize detail, including defects in photoconductors, has inspired many proprietary efforts to develop optical mapping systems. In general, these efforts have been unsuccessful due to problems with speed, reliability, and flexibility. Furthermore, optical measurements are fundamentally indirect: a cosmetic defect may affect a photoconductor's appearance without any degradation in its performance, while a serious functional defect may be optically invisible.

A more reliable approach than any of these is electrostatic mapping based on direct measurement of the photoconductor's electrophotographic properties. This approach, now commercially available[14], uses a proven electrostatic measurement technology — non-contact electrostatic voltage probes with vibrating electrodes. Unlike the other systems, this mapping system simulates the electrophotographic printing process and is designed to measure specifically those defects that affect print quality. It provides invaluable data in both R&D and production applications for materials development, process development, and quality control.

Figure 1 illustrates an electrostatic mapping system. A brief discussion of each system component follows.

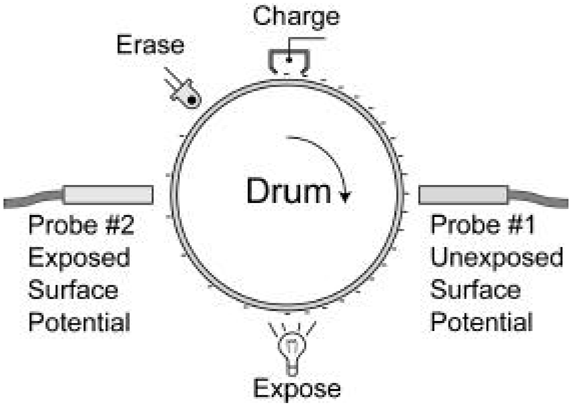

Figure 1 Electrostatic mapping system measurement principle

Design of an electrostatic mapping system – system components

Scanner

To map the entire photoconductor surface, two-dimensional scanning capability is required. In general, one axis (the indexing axis) is stationary during measurement while the other axis (the scanning axis) is in motion. When the scanning axis reaches the end of one cycle of motion, the indexing axis advances one step and the process is repeated until the entire photoconductor surface has been measured. Figure 2 illustrates some scanning geometries used in commercially available systems. Although only cylindrical photoconductors are shown, belts and other photoconductor types can also be scanned.

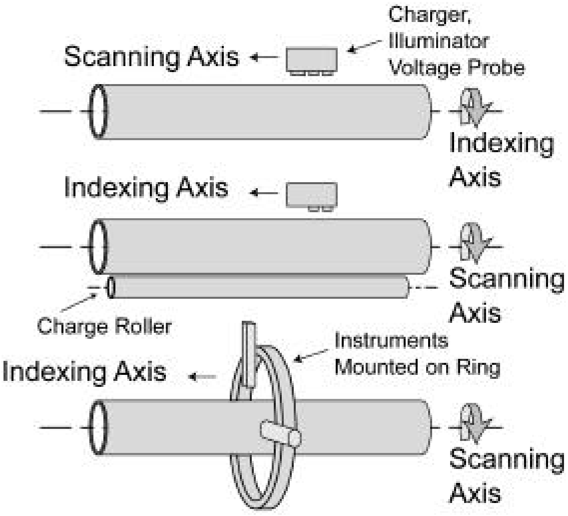

Figure 2 Some two-dimensional scanning geometries

Charging subsystem

The photoconductor is charged with either a corona-type charger or a charge roller. Often the charging system is selected to simulate the charging conditions in the ultimate application — the printer. However, since printer charging systems are usually optimized to tolerate photoconductor variations, this approach is inappropriate for characterizing subtle non-uniformities in the photoconductor. In such cases, often in R&D applications, the charging system is designed to increase system sensitivity to photoconductor variations. A versatile mapping system must include a charging subsystem capable of charging with either positive or negative polarity.

Exposure subsystem

Any of a variety of exposure sources is available, including LED, tungsten halogen with filters, or laser scanner. The choice of exposure source is governed by the types of analyses to be performed. For example, to simulate the printer environment as closely as possible, a scanning laser is indicated. However, for maximum flexibility, a tungsten halogen source in combination with interference filters makes it easy to change exposure wavelengths for characterizing the photoconductor's spectral sensitivity.

Erasure subsystem

The erasure subsystem is either a bank of LEDs, as in most printers, or a charge roller, as in printers with charge roller charging subsystems.

Measurement subsystem

Non-contact electrostatic voltage probes and meters are used for measurement. The voltage resolution of these probes is what principally determines the sensitivity of the mapping system. Similarly, the spatial resolution of the probes

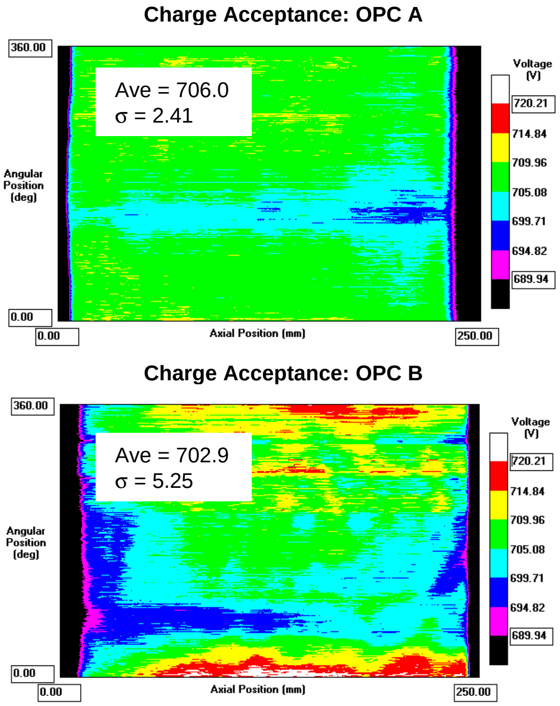

Figure 3 Photoconductor charge acceptance uniformity mapping[*] (Ave = average of entire voltage map; σ = standard deviation of entire voltage map)

controls the size of the smallest local defects that can be resolved. Another important characteristic of the probes is their dynamic response: Too slow a response unduly limits the maximum scanning speed allowed for acceptable results.

State-of-the-art software, controls, and capabilities

State-of-the-art electrostatic photoconductor mapping systems now available are equipped with powerful software for programming and control of all subsystems and test parameters: linear scanning speed (up to 50 cm/sec), rotational speed (up to 5 revs/sec), percent coverage, photoconductor conditioning, charging and exposure parameters, and erase parameters. Data are acquired and stored in digital format. Analysis is aided by tools such as false-color uniformity maps, voltage and current statistics, and automated quality control pass-fail determinations. The software is optimized for ease of use without sacrificing power or versatility.

An important feature of commercially available systems of this type is the ability to test a wide range of photoreceptor sizes and designs by the use of interchangeable adapters.

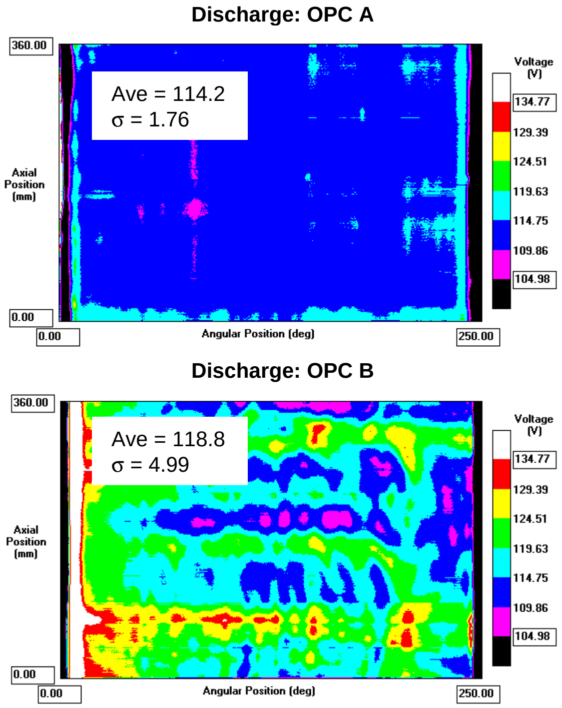

Figure 4 Photoconductor discharge uniformity mapping

Charging and discharge uniformity mapping – examples

Figure 3 shows charge acceptance maps from two different organic photoconductors (OPCs). As the color maps and statistics show, OPC A is much more uniform than OPC B. Charging uniformity is directly related to uniformity of coating thickness, among other coating variables.

Figure 4 shows discharge maps from the same two OPCs as in Figure 3. Discharge non-uniformity leads to non-uniformity in print density and is therefore a major contributor to image noise.

Uniformity mapping with charge roller charging – examples

The charge acceptance maps in Figure 5 correspond to different combinations of charge rollers (new or worn) and OPCs (again, new or worn). Notice that if either the charge roller or the OPC is worn, non-uniformity in charge acceptance results. In fact, in this example the condition of the charge roller is much more important than the condition of the drum with respect to uniformity. This example illustrates the unique capability of electrostatic mapping tools in evaluating and understanding not only OPCs but also charge rollers and OPC/charge roller compatibility.

Monitoring wear of photoreceptors — examples

Figure 6 compares two OPCs of the same type – one new and the other used for approximately 5000

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[*] Although this publication is monochrome, **all** map images originally appear with color.

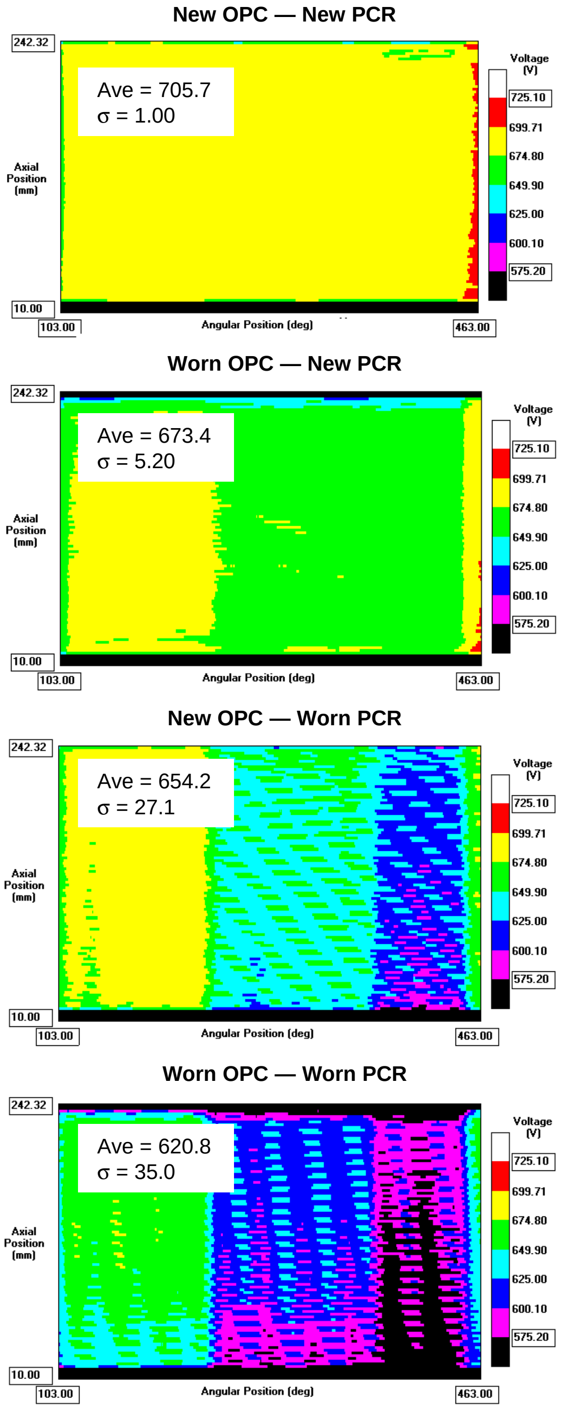


Figure 5 Photoconductor charge acceptance uniformity mapping using different photoconductor and charge roller combinations.

pages. Note that not only is the worn OPC less uniform, but the mean acceptance voltage is considerably lower. This example illustrates the ability of the electrostatic mapping system to reveal wear patterns, making it possible to estimate remaining coating thickness.

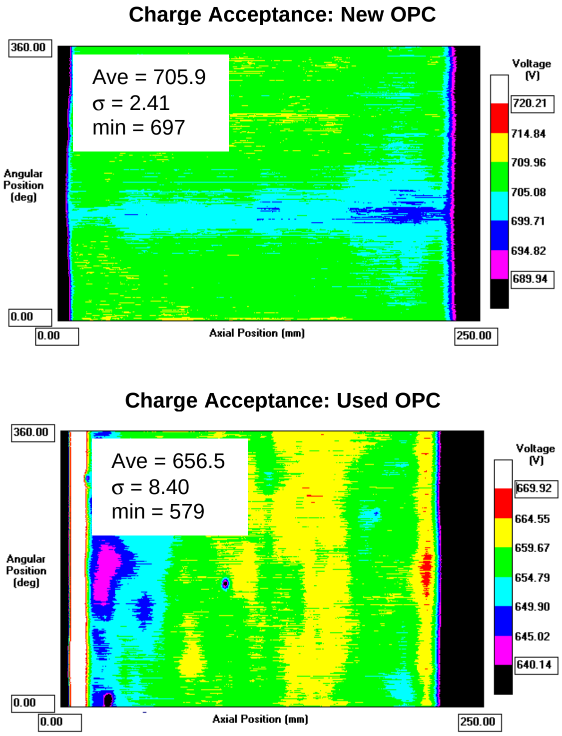


Figure 6 Photoconductor charge acceptance uniformity mapping

Figure 7 shows the correlation between mean charge acceptance measured by the electrostatic mapping system and thickness measured by a contact eddy current thickness gauge, confirming the mapping system results.

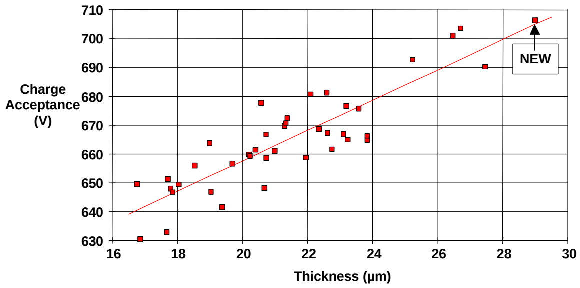


Figure 7 Correlation between charge acceptance and coating thickness

In another illustration of wear monitoring, the histogram in figure 8 shows the variations in mean acceptance voltages of a batch of 100 used OPCs. The average drum voltage reveals the variability of wear in OPCs of identical type subjected to the same level of use. This kind of wear data offers invaluable insight into OPC reliability for product development.

In sum, degradation in print quality occurs over time primarily because of coating wear. The electrostatic mapping systems now available

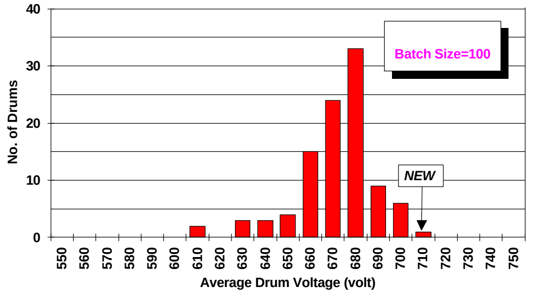


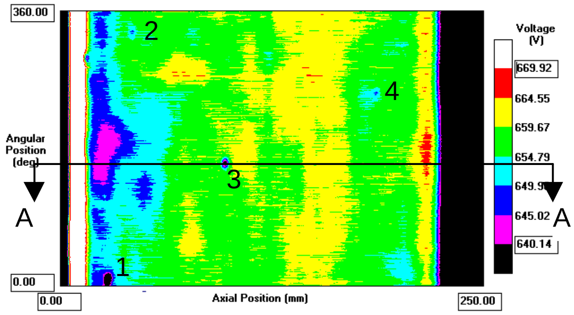
Figure 8 Average charge acceptance voltages from a batch of 100 used photoconductors.

facilitate rapid detection, measurement, and analysis of this critical data.

Defect mapping — examples

Figure 9 is a charge acceptance map of an OPC with four pronounced defects (numbered 1-4 in the figure). This voltage map and the corresponding voltage profile show both localized and overall wear. Since electrostatic mapping is a direct measure of the electrophotographic characteristics of the OPC, there is a very high probability that defects seen in this map will produce print defects. In fact, experimentation proves that for the OPC illustrated in Figure 9, the four mapped defects actually do produce objectionable print defects.

Charge Acceptance: Used OPC



Charge Acceptance: Voltage Profile across A-A

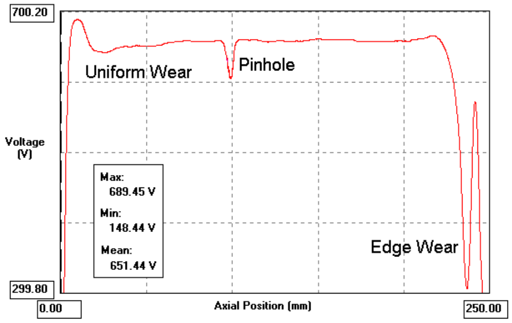


Figure 9 Photoconductor charge acceptance uniformity mapping

It should be noted that discharged voltage mapping (not shown) can also reveal important defects.

Using standard electrostatic voltmeters, pinholes as small as 50 – 100 µm can be detected. Typically, through-thickness pinholes are easier to detect than subsurface defects. It is important to understand that while the physical dimensions of a pinhole may be very small, the disturbance it creates in the electrostatic field affects a much larger area. A 50 µm diameter pinhole, for example, may affect an area as large as 1000 µm in diameter. Thus, the dimensions of pinholes and other local defects appear significantly magnified in the map.

This distortion of the electrostatic field means that detecting defects is much easier than characterizing them, although there is a clear relationship between defect size and voltage depth. When detection is the primary goal, scanning of individual photoreceptors can be sped up significantly to reduce total scanning time. (It should be noted that scanning time depends on the percent coverage desired and the scan speed and ranges from less than a minute to about twenty minutes.) Detection sensitivity can also be improved by imposing a higher nominal voltage, thereby enhancing the voltage differential between a defect and the area surrounding it.

Discussion

The examples reported in this paper demonstrate just a small subset of the possible uses of an electrostatic mapping system for photoconductors. The major design requirements of such a system include: a) simulation of the printing process; b) non-destructive, non-contact measurement techniques; c) ability to test a wide range of photoreceptor types; d) a high degree of programmability; e) quantitative measurements; f) ability to detect and localize defects.

A family of state-of-the-art test systems for electrostatic mapping of photoreceptors is now available for a variety of applications and in a range of capabilities, sophistication, and prices. The applicability of such systems to charge roller testing has also been demonstrated. Further, electrostatic mapping systems are applicable to all photoconductor types (including OPC, amorphous silicon, and other inorganic photoconductors) and designs (including drums and belts).

The approach to photoconductor mapping described in this paper is very effective. On-going developments include improved methodologies for defect characterization; improved spatial resolution; and high-throughput for manufacturing QC systems.

Conclusions

This paper presents an innovative photoreceptor mapping technique. The technique uses instrumentation to simulate printing conditions and uses non-contact, non-destructive electrostatic voltage measurements to map the electophotographic properties of the photconductor. Examples demonstrate the efficacy of this technology for both R&D and quality control applications:

1. Electrostatic thickness and wear monitoring is a non-destructive, non-contact scanning alternative to conventional eddy current methods.
2. The correlation of discharge mapping to optical density in print tests is an insightful and powerful application of electrostatic mapping.
3. The use of electrostatic mapping to study photoconductor/charge roller interactions is innovative and reveals the importance of the charge roller in print uniformity.
4. Electrostatic mapping can be used to detect defects much smaller than the specified resolution of the probe used, since the distortion of the electric field near a defect has a magnifying effect.
5. Although an electrostatic mapping system can be designed to simulate the printing process, the instrumentation must be sensitive to the characteristics to be measured. That is, the system should be designed for measurement, not for printing.

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