# Predicting Print Quality in Electrophotography Using Electrostatic Charge Decay Measurements on Development Rollers

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## Abstract

The quality of the printed output from an electrophotographic printer or copier is determined by the performance of, and the interactions among, the major components in the system: namely, the photoreceptor, the charging subsystem, the exposure subsystem, and the development subsystem. The existence of the many variables which affect component interactions make prediction of print quality quite difficult. However, if we confine our attention to any one of the subsystems, or a single component of a subsystem, we can correlate print quality with the characteristics of the component(s) involved. In this paper, the electrostatic charge decay (ECD) technique is used to evaluate the development roller (or mag roller) employed in popular low speed electrophotographic printers and copiers. This technique measures the conductivity of the surface coating on the development roller non-contactly and nondestructively. Using these measurements, the propensity for ghosting and drop-off in print density can be predicted. The principle underlying this technique and the design considerations for a practical measurement system suitable for product development and manufacturing quality control will be discussed.

## Introduction

This paper focuses on magnetic, monocomponent development systems commonly used in low speed laser printers. During the development cycle in these printers, the electrostatic image is developed into a visible image on the organic photoconducting drum (OPC) when toner on the surface of the development roller (which will be referred to as the "mag roller" in the rest of this paper) is transferred to discharged areas on the drum (Fig.1). The quality of the image, which ultimately determines the print quality, depends on the charge and discharged level of the OPC, the charge level of the toner, and the bias voltage on the mag roller. In the development process, the mag roller serves to charge the toner by friction (tribo-electrification) and to deliver the charged toner to the development zone. Two types of print quality problems, ghosting and drop-off in density, have been identified to be caused at least partially by the mag roller failing to perform its intended functions. Canon's approach to overcome these problems is to use mag rollers coated with a polymeric resin containing conductive graphite particles or other conductive fibers.[1] The basic idea is that small toner particles (<5-6µm), which acquire too high of a charge and are strongly adhered to the roll surface by an electrostatic image force, can prevent new toner from being adequately charged, particularly under low humidity conditions. By having a more conductive mag roller, some of the undesirable high charge will be conducted away from the toner adhered to its surface, thereby restoring its ability to charge new toner.[1] From this discussion, it is obvious that controlling the conductivity of the development roll surface is a key to minimizing the print quality problems of drop-off in density and ghosting. The conductivity of the mag roller must be sufficiently high to totally relax the charge on any unconsumed toner particles adhered on its surface within one full revolution of the roller. In the common low speed laser printers, the time for one full mag roller revolution, and therefore the maximum charge relaxation time, is on the order of one second or less. To achieve this level of relaxation time, the thickness of the resin coating should be thin and its resistivity should be relatively low. Some typical limits on the coating thickness and resistivity reported in the literature are less than 10 µm and $10^2$ ohm-cm respectively.[1]

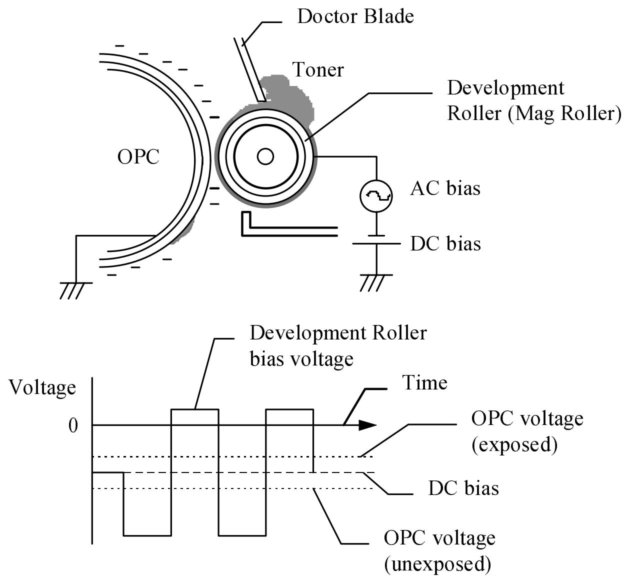


*Figure 1. Developing an Image on the OPC in a Magnetic Monocomponent Development System*

Controlling the mag roller coating thickness and its resistivity is vital to its performance. In this regard, an important issue relating to the quality of mag rollers arises as the remanufacturing of toner cartridges increases in popularity. In toner cartridge remanufacturing, a challenge is to determine the reusability of recyled mag rollers or the suitability of aftermarket mag rollers. In this paper, the ability of a novel electrostatic charge decay (ECD) technique[2] to meet this need is examined. The main objective is to explore if a correlation exists between ECD measurements and the print quality problems of ghosting and drop-off in density. The principle of ECD is to deposit a static charge on the surface of a material, and monitor the rate at which the charge dissipates (decays) through the material. Intuitively, one would expect that the residual voltage measured by the ECD technique should reflect the conductivity of the mag roller, and therefore should predict print quality.

## Experimental Method

### Electrostatic Charge Decay (ECD) Technique

A schematic of the electrostatic charge decay (ECD) equipment used in this study is shown in Fig. 2. The specific equipment used is a commercially available, computer-controlled mag roller test system (MRT-2000, Quality Engineering Associates, Inc.). This system employs a scorotron type corona charger to deposit a charge on the surface of a mag roller and a non-contact electrostatic probe to measure the residual voltage on the roller surface at a fixed time interval following charge deposition. The time interval between charging and measurement was typically 0.25 seconds. Under computer control, two basic scanning modes are used to characterize a mag roller: 1) *residual voltage map* - in which the residual voltage on the entire mag roller is measured, one track at a time along the axis of the roller, with the roller indexed circumferentially in between tracks, until the entire roller surface is covered; and 2) *charge accumulation test* - in which a single track on the roller is repeatedly charged and scanned to measure the accumulation of residual charge. In the charge accumulation test, the time lapse between successive scans is approximately 5 seconds. In both residual map and accumulation test, the statistics of the residual voltage along each track (or scan) are computed and reported.

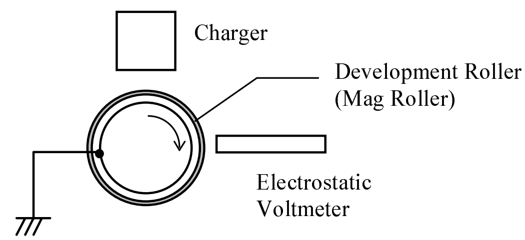


*Figure 2. Schematic of Electrostatic Charge Decay Measurement*

### Materials and Preparation

Twenty-five mag rollers from Hewlett-Packard Laserjet Series 4 (EX) laser printers were tested. This collection of OEM rollers, which all have a black polymeric surface coating, includes both brand new, unused rollers, as well as rollers retrieved from used cartridges. The rollers studied thus comprise a range of usage histories and surface conditions. The used mag rollers were cleaned by vacuuming and blowing with compressed air to remove the residual toner. Some rollers were also conditioned (i.e. recoated or polished) to modify their surface characteristics and thereby broadening the range of sample conditions. In addition, two rollers were polished using very fine emory paper to remove most of the black polymeric coating to expose the underlying aluminum substrate.

### Print Tests and Test Target Design

Each mag roller was installed in a standard EX toner cartridge to print multiple copies of test pages consisting of: 1) a solid black page to evaluate black density, and 2) a black-and-white checker pattern followed by a solid black area to evaluate the severity of ghosting. In the checkered page, the height of each square is one fourth of the mag roller circumference. Each checkered page consists of 8 rows of such alternating black and white squares for a total of two complete mag roller revolutions. The idea behind this test print design is twofold: 1) the effect of mag roller on print quality can be separated readily from those of other components (e.g. OPC and charge roller), since the circumference of the mag roller is an integral multiple of the checker squares; and 2) the alternating black-and-white checkers are expected to cause ghosting in the solid black area that immediately follows the checkers, if the unconsumed toner in the white squares reduce subsequent toner charging and hence the density of the corresponding locatons in the solid black area. The print outputs were analyzed using an automated image analysis system (IAS-1000, QEA)[3] to measure the image density and the ghosting severity. Ghosting severity is defined by the difference in optical density at adjacent locations in the solid black area corresponding to the adjacent squares in the previous checker pattern. When ghosting occurs, the density variation in the solid black area is usually quite obvious. During print tests, both a new and a worn OEM OPC were used with all mag roller samples to explore the interaction between the mag roller and the OPC. OEM toner from a standard cartridge was used in all print tests.

## Results

The results of this study on solid black density and ghosting are summarized in Figs. 3-6, with data from both a new and a worn OPC. Fig. 3 shows the correlation between the average ECD voltage obtained in the full-body map of each mag roller and the optical density of a solid black page.

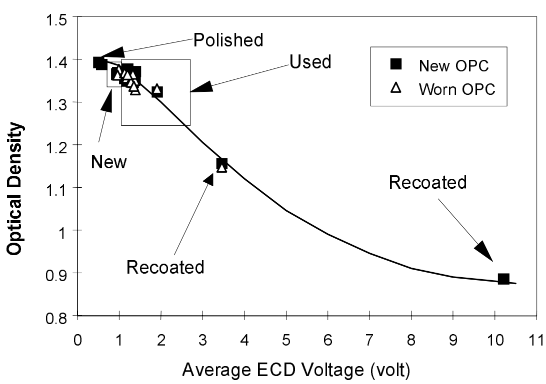


*Figure 3. Correlation between Optical Density in Solid Black Area with Average Residual Voltage from ECD Mapping.*

Fig. 4 shows a similar correlation between the average ECD voltage and the ghosting severity measured in terms of the variation in optical density in the solid black area.

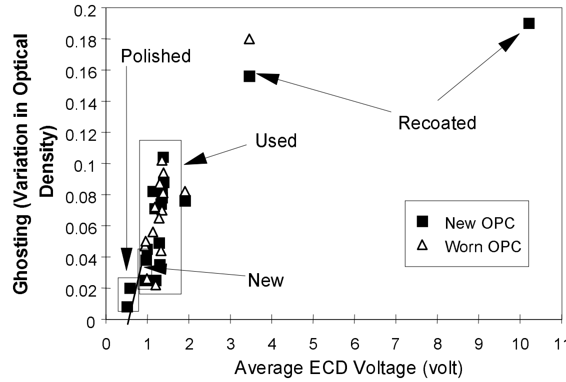


*Figure 4. Correlation between Variation in Optical Density with Average Residual Voltage from ECD Mapping.*

Fig.5 is similar to Fig.3, except that the solid black density is plotted against the increase in ECD voltage from the first to the last scan in a 40-scan charge accumulation test.

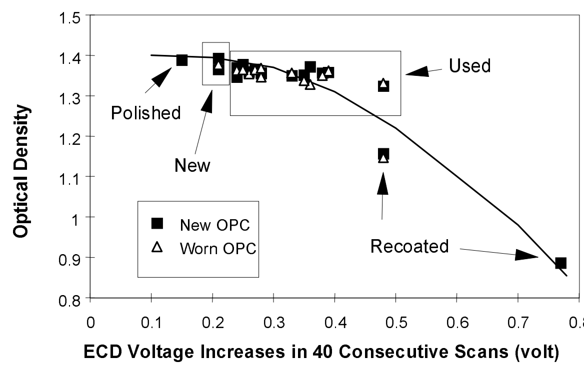


*Figure 5. Correlation between Optical Density in Solid Black Area with ECD Voltage Increase in Charge Accumulation Test.*

Fig.6 is similar to Fig.4. In this figure, the relationship between ghosting (i.e. variation in optical density in the solid black area) and ECD voltage increase is depicted.

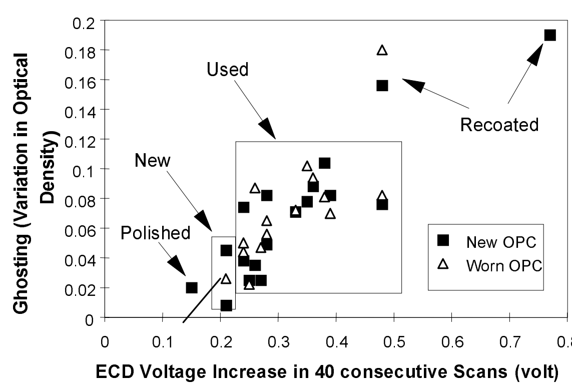


*Figure 6. Correlation between Variation in Optical Density with ECD Voltage Increase in Charge Accumulation Test.*

All the above figures contain data obtained with both new and worn OPCs. No apparent difference in density level and ghosting severity between the new and the worn OPC is observed, suggesting that the condition of the mag roller, not that of the OPC, is the controlling factor in these experiments. To provide further insight into the relationship between the condition of the mag rollers and print quality, the surface condition and the usage history of the mag rollers are also indicated in these figures. As shown, the quality of the mag rollers can be ranked on the basis of decreasing solid black density and increasing ghosting severity in the order of: polished, new, used, and recoated. The numerical values of the average map voltage and voltage accumulation for these four category of samples are summarized in Table 1:

***Table 1: Numerical summary of average map voltage and voltage increase in accumulation test.***

| Sample Type | Average Map Voltage (volt) | Voltage Accumulation (volt) |
|---|---|---|
| Polished | 0.5 | 0.15 |
| New | 1.0 | 0.20 |
| Used | 1.0 - 2.0 | 0.20 - 0.50 |
| Recoated | >3.0 | >0.50 |

The corresponding solid black density and ghosting (measured by the variation in solid black density) are summarized in Table 2:

***Table 2: Numerical summary of solid black density and ghosting.***

| Sample Type | Solid Black Density | Ghosting (Variation in Optical Density) |
|---|---|---|
| Polished | 1.4 | <0.02 |
| New | 1.38 | 0.025 |
| Used | 1.25-1.38 | 0.02-0.11 |
| Recoated | <1.2 | >0.15 |

It is apparent from the above results that the trend in the average residual voltage in mapping and the voltage increase in charge accumulation are quite similar. This similarity suggests that the two measurements are related, and probably have the same physical origin. Indeed, the correlation between the two measurements as shown in Fig. 7 confirms this point.

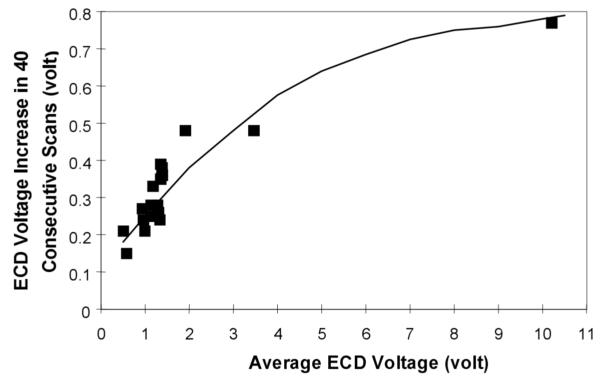


*Figure 7. Correlation Between Charge Accumulation Test and Residual Voltage Map*

## Discussion

The conductivity of the mag roller is an important factor in print quality and should therefore be monitored and controlled carefully. However, measuring the conductivity of mag roller reliably is no easy task because the thinness (< 10 µm) and the low resistivity of the surface coating make it difficult to apply conventional contact surface resistivity measurement techniques. The ECD technique introduced in this study offers a novel solution to this problem. The non-contact and non-destructive nature of the proposed technique is ideal for this application as demonstrated in this study.

Two methods for mag roller characterization based on ECD were examined. Both methods, namely, measuring the average voltage in residual voltage mapping and the voltage increase in accumulation test, appear to provide similar information on solid black density and ghosting severity. The two measures are in fact related and are likely to have the same physical origin (i.e. the resistance of the mag roller). Therefore, in practice, only one of the measures may be necessary to provide sufficient information to assess a mag roller.

The ranking of the mag rollers tested in this study in the order of decreasing solid black density and increasing ghosting severity is in polished, new, used, and recoated. Both the average residual voltage and the voltage accumulation are the lowest for the polished sample. This observation is consistent with the fact that the polished sample has the thinnest polymeric coating and therefore is most likely to have the lowest resistance. Based on this observation, it may be tempting to conclude that no coating may even be needed for good density and ghosting results. However, it must be emphasized that the original black coating on the mag roller must have been optimized by its manufacturer to provide the proper level of triboelectric charging of the toner, as well as to ensure long term reliability in the roller's performance. Any attempt to alter the surface characteristics, e.g. by polishing (or sand blasting) to remove the surface coating is likely to introduce unexpected problems. On the other hand, the very poor density and ghosting results from the recoatings used in this study may be misleading also. Based on the poor results, one may conclude that recoatings are not good for reconditioning of a mag roller for the purpose of reviving its usability. However, the recoatings studied here are by no means optimized, and are not representative of all recoatings that are available, or yet to be developed. The recoating results reported here should therefore be viewed as merely an illustration of the use of the ECD technique for mag roller screening or recoating development, and not a definitive statement on the effectiveness of the recoating technique.

Despite the complexity of the electrophotographic process in general, and the development process in particular, the results in this study are very encouraging. The potential of using the ECD technique as a predictive tool for mag roller performance in terms of solid black density and ghosting severity is clearly demonstrated. For example, focusing on the range of data for the used mag rollers, both the residual voltage and the charge accumulation measurements appear to be capable of differentiating the different levels of performance, supporting the usefulness of the ECD technique. However, acknowledging the complexity of the electrophotographic process, further study will undoubtedly be necessary to clarify the effect of many complicating factors in this measurement technique, such as the effects of high and low humidity, toner charging, and the surface roughness of the mag roller.

## Conclusions

The efficacy of a novel electrostatic charge decay (ECD) measurement system for predicting mag roller performance in monocomponent development is demonstrated in this study. Using this system, solid black density and ghosting severity were found to correlate with the residual voltage and the charge accumulation on the mag roller. Both residual voltage and charge accumulation are determined by the charge relaxation characteristics of the mag roller; and the results suggest that the effectiveness of the two measures are in fact quite comparable.

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