The Effect of Magnetic Roller Field Uniformity on Print Quality in Electrophotography

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Abstract

The magnetic roller is a critical component in magnetic development systems in electrophotography. It serves to meter and deliver a uniform layer of toner to the development zone and to control the amount of toner delivered onto the photoreceptor. To ensure good print quality, the magnetic field around the roller must be designed properly and controlled carefully. In this paper, the effect of magnetic field non-uniformity on print quality is studied. The efficacy of a commercial magnetic roller mapping instrument for measuring and quantifying magnetic flux density characteristics is also investigated.

Introduction

Magnetic development systems are in widespread use in desktop printers, copiers and fax machines. These systems consist of many complex components each of which contributes to overall print quality[1]. Design tolerances and manufacturing variations in these components contribute to the overall printer error budget and thus affect print quality. One challenge for designers and manufacturers is to control the amount of variation in each critical component. Accomplishing this objective requires tools for measuring component parameters accurately and reliably. Additionally, for economic and ecological reasons a growing percentage of laser printers, xerographic copiers, and toner cartridges is now being recycled. As critical components are reused - perhaps many times - another challenge is to determine which ones are good for another full cycle of use, and this again calls for accurate and reliable measurement techniques.

One type of magnetic development system is the monocomponent, jumping development system shown in Figure 1. In this implementation, a key component is the magnetic roller, which comprises a stationary magnetic core and a rotating outer sleeve. During the development process, the magnetic core inside the roller exerts a force that attracts the toner from the toner hopper onto the outer magnetic sleeve. The amount of toner transported into the development zone is metered by the doctor blade located at the exit of the toner hopper. Finally, in the development zone, the toner is selectively transferred from the development roller onto the photoreceptor. The motion of a toner particle in the development zone is governed by the electrostatic force exerted by the electric field between the magnetic roller and the photoreceptor, and the magnetic force exerted by the magnetic field surrounding the magnetic roller. The magnetic force provides a convenient means of controlling the toner particle motion and is therefore a critical factor in the toner development process that ultimately affects the quality of a print.

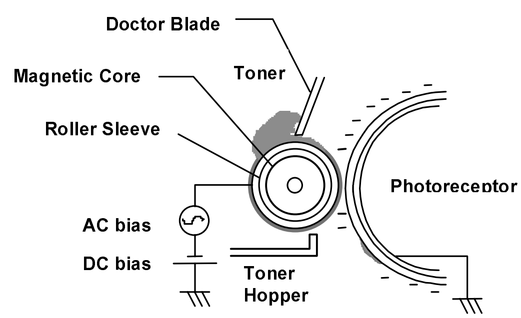

Figure 1. A Monocomponent, Magnetic, Jumping Development System

In this paper, we will demonstrate the effect of magnetic field variability on print density and background. We will also explore the efficacy of a commercial apparatus for scanning and quantitatively mapping the field surrounding a magnetic core. Using this apparatus, we will establish the correlation between the magnetic field and print quality.

With this apparatus, the magnetic field is measured using a Hall-effect probe, and the measured quantity is

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magnetic flux density, B. The unit of measurement is Gauss. In this paper, we will use the terms magnetic field and magnetic flux density interchangeably.

Function of the Magnetic Core

The core in a magnetic roller serves three important functions in the development process[2-3]. The first of these is to work in conjunction with the doctor blade to meter a controlled layer of toner onto the rotating magnetic sleeve. The second is to magnetically hold the toner to the sleeve while it is transported to the development area. The third is to provide a force opposite to the electrostatic force in the development zone to permit controlled development of the image. To adequately fulfill each of these functions, the magnetic force holding the toner particle to the magnetic roller must be carefully controlled.

The magnetic core is typically multi-poled. The pole locations are designed to permit independent control of the magnetic forces in the metering and development zones. Thus, the magnetic forces around the circumference of the roller are not constant, but are deliberately varied to serve different functions.

The magnetic force that holds a toner particle to the magnetic sleeve is a function of the magnetic moment of the particle and the magnetic flux density gradient at the location of the particle, as shown in Fig. 2. The magnetic moment of the particle is determined by the amount of magnetic material it contains and by its shape and size. The magnetic flux density gradient is determined by the strength and geometry of the magnetic poles around the circumference of the magnetic roller[4].

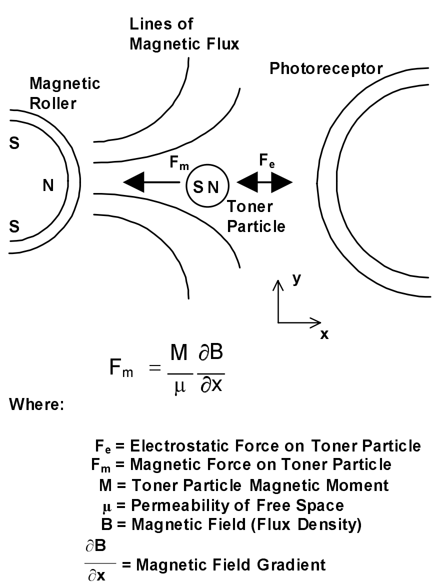

Figure 2. A Toner Particle in the Development Zone.

General Requirements for a Magnetic Core Tester

To control the quality of a magnetic core and to predict its performance, we must be able to measure the flux density in the vicinity of the core, both around its circumference and axially along its length. To accomplish this, the measurement instrument must be capable of scanning the magnetic core in a controlled manner to completely characterize the flux density and distribution surrounding it. Topographical maps of the flux density should also be available. These depict the field uniformity in a quantitative and graphical manner that is both easy to assimilate and immediately useful in research, product development, and production quality control. Figure 3 shows a schematic diagram for a commercial magnetic field mapping system (QEA MFA-2000). Using this system, 2-D maps of the magnetic field (in this case the radial magnetic field) surrounding a core can be obtained quickly, under computer control.

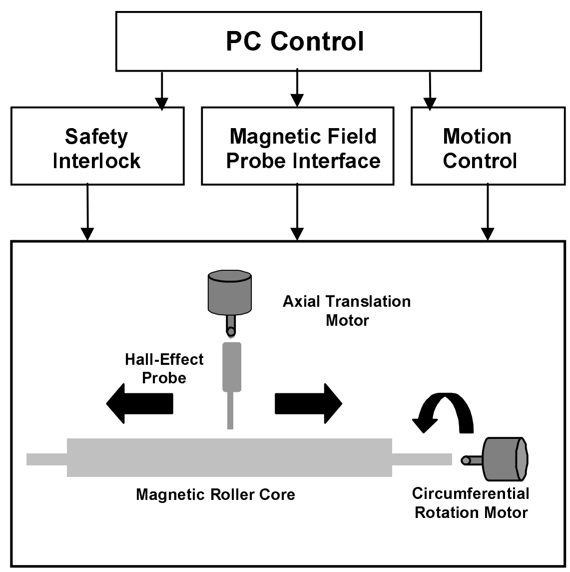

Figure 3. Schematic Diagram of a Magnetic Field Mapping Instrument

Application of the Instrument to the Analysis of Magnetic Roller Cores

As noted, the magnetic roller core performs three important functions in the development process. For the purposes of this study we will focus on the development zone and investigate how magnetic flux density variations in this zone affect print density and background.

Experimental Method

For our print quality study we selected an HP LaserJet 4 as an example of a widely used printer that uses a monocomponent, jumping development system. In preference to producing several magnetic roller cores, each with a different magnetic field, we created a single core with several step changes in field along its length. At several points along the axis of the core, the flux density was permanently reduced by opposing it with the field of a strong permanent magnet. The magnetic field of the modified core was then characterized by means of our field-mapping instrument. Finally, the modified core was installed in a toner cartridge for print testing. To explore the effects of reduced magnetic field on print density, a test target with step increases in gray level was used. To investigate similar effects on background, white pages were printed. The print test results were then quantified with an automated print quality analysis system (QEA IAS-1000). Figure 4 shows a typical image obtained from the print density test.

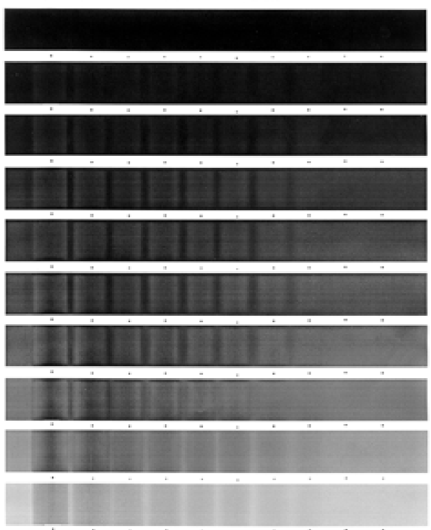

Figure 4. A Typical Gray Scale Test Print

Results and Discussion

Effect of Magnetic Field on Optical Density

The upper half of Figure 5 shows printed images at 10% to 50% gray levels; the lower half shows a plot of magnetic field gradients in the development zone for the modified roller core. Comparing the printed images and the magnetic field data, it is apparent that the step reductions in magnetic field gradient result in successively higher print densities. This empirical result is summarized quantitatively in Figure 6, which shows that at a 70% gray level and below, the optical density measured is inversely proportional to the magnetic field gradient. At higher optical densities, however, the effect is much less visible.

The empirical correlation between optical density and the magnetic field gradient in the development zone can be explained by the fact that the magnetic force serves to oppose the flight of a toner particle towards the photoreceptor. Since the magnetic force is proportional to the magnetic field gradient, as illustrated in Figure 2, it is not surprising that a reduction in the field gradient will lead to an increase in the number of toner particles landing on the photoreceptor, thereby increasing the optical density of the finished print. However, at high gray levels, the effect of the magnetic force appears to be overshadowed by the strength of the electrostatic force, which serves to attract a large enough amount of toner onto the photoreceptor to produce a dark solid area.

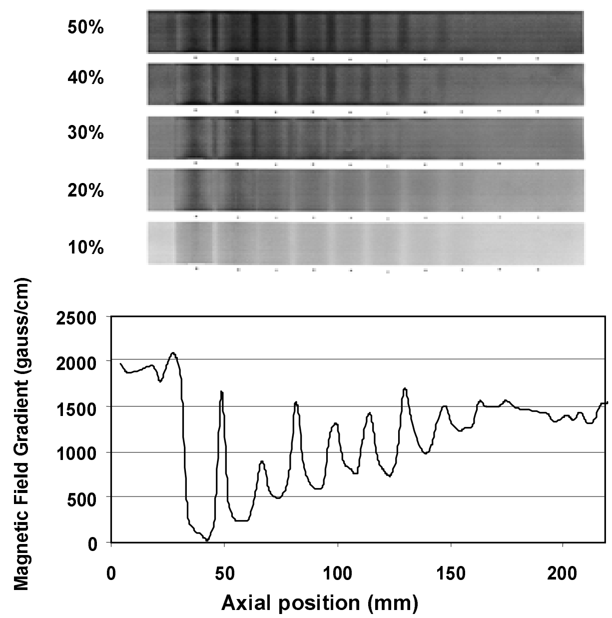

Figure 5. Section of a Test Target Shown with a Plot of the Corresponding Magnetic Field Gradient

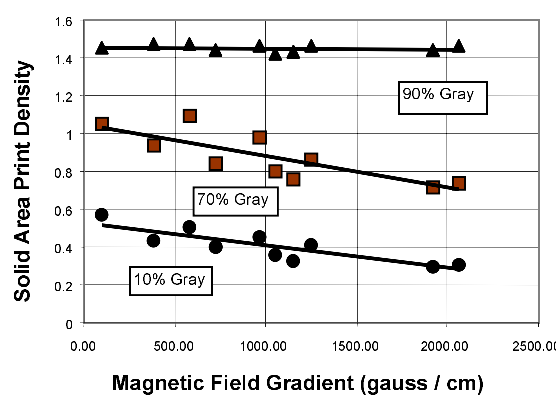

Figure 6. Correlation between Solid Area Print Density and Magnetic Roller Core Magnetic Field Gradient

One practical application of the results shown in Figure 6 is setting acceptance standards for quality control of magnetic cores. Using as a benchmark visual sensitivity to optical density at various gray levels, we can estimate the tolerance limits for the magnetic field gradient from the data shown in Figure 6, as discussed below.

Effect of Magnetic Field on Background

The effect of magnetic field gradient on background development in white test prints was also examined. Background was characterized by measuring reflectance in each of the zones of reduced field gradient. The results are shown in Figure 7.

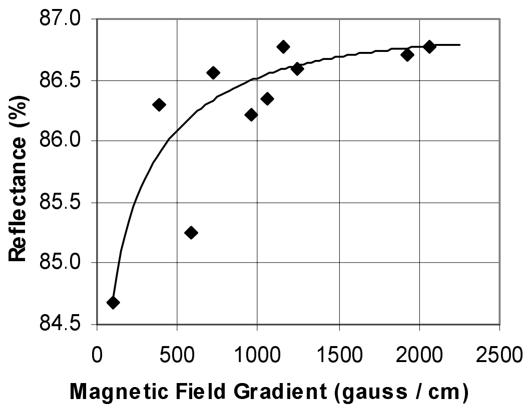

Figure 7. Correlation between Background and Magnetic Field Gradient

It is clear from Figure 7 that the amount of background development depends quite strongly on magnetic field gradient. As shown, background is much less sensitive to field gradient variations at higher gradients but increases rapidly as the gradient is reduced. Visually, the background level is quite objectionable at field gradients below approximately 1000 gauss/cm.

How consistent do magnetic roller cores need to be?

From a practical point of view, how consistent do magnetic roller magnets need to be? What is the consequence, for example, of manufacturing defects that result in a 10% decrease in magnetic flux density gradient? Our study shows that the darkest areas of solid fill are unaffected. Gray areas, in contrast, demonstrate obvious increases in optical density, with lighter gray areas showing the greatest deviations. For example, a gray area with a normal optical density of 0.33 shows a very noticeable increase in density of almost 6%, a very significant difference. Background on white areas deviates by only about 0.025% from nominal reflectance values of 86.7%—a visually undetectable difference. Overall, lighter gray areas demonstrate the greatest sensitivity to field gradient variations. While the absolute performance limits of any individual component must be dictated by the specific application, it is clear that noticeable changes in gray density can be caused by small changes in magnetic roller core flux density gradient.

Conclusions

This study demonstrates the efficacy of a magnetic field mapping apparatus for quantifying the magnetic field and its gradient around the core of a magnetic roller.

The utility of the instrument was demonstrated in an experiment designed to determine the effect of magnetic roller core flux density gradient variation on solid area print density and background development. The resulting data can be used for making accept/reject decisions in manufacturing and recycling operations and can provide valuable process control information for minimizing print quality defects.

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Biography

Joseph J. Burbage is a Research and Development Engineer with Quality Engineering Associates. Mr. Burbage received his Bachelors Degree in Electrical Engineering from the Massachusetts Institute of Technology in 1974 and his Masters Degree in Electrical Engineering from Northeastern University in 1986. He is a member of IS&T and the IEEE.