A New Electrophotographic Developing System with a Sleeve Free Magnet Roller

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A new electrophotographic developing system was created to simplify the developing unit. The new developing unit is simple and features a hot spatial ??? frequency magnet roller without a sleeve. The sleeveless magnet roller was made of a sintered ferrite magnet 20 mm in diameter and magnetized with 32 poles. This developing system can be applied to both mono-component magnetic toners and conventional dual-component developers. Factors and developing conditions that influence image quality were examined using a variety of developers where both the toner and carriers were magnet. Images printed with the new developing unit were not influenced by either toner concentration or electric resistivity of the carrier, but were affected by the size of the carrier. The best image quality was obtained by using a carrier 35 μm in diameter. The new system demonstrated print image quality that was nearly as high as that produced by conventional developing units with a sleeve.

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Introduction

Electrophotography originally employed cascade development.[1] Shortly after, magnetic brush development was invented and applied to photocopying machines.[2] Today electrophotography is still progressing to higher speeds and resolutions and extending its application field to printers, facsimile machines, and color electrophotography. Recently, many trends, such as down sizing, solving ecological problems, reducing costs, etc. have posed challenges to electrophotographic technology, but have also improved its performance. For example, some products recycle waste toner by conveying it from the cleaning unit back to the developing unit. Toner remaining on the photoconductor after transfer is also removed and conveyed to the developing unit by the developing roller.[3–5] Another conservation effort is to reduce energy consumption in heat fusers by modifying the heater structure and reducing the melting temperature of the toner.

We call our new electrophotographic developing system "sleeveless." The new system is simple and sleeve-free. This article describes fundamental properties of the sleeveless developing system. Factors that influence image quality in this system will be discussed.

Experimental

Structure and Materials of the Magnet Roller for the Sleeveless Developer System. Figure 1 shows schematic drawings of the newly developed sleeveless electrophotographic developer unit and a conventional developer unit with a sleeve for comparison. A conventional developer unit usually consists of a rotating nonmagnetic stainless steel sleeve and a fixed magnetic roll, which is magnetized with four poles and mounted inside a sleeve. In contrast to the conventional magnetic brush, the new developer unit only consists of a symmetrically magnetized rotating magnetic roll without a sleeve. The number of magnetic poles on the roll must be large compared to a conventional roll.

In the study, a 32-pole roll magnetized to 0.035 T was used. This enables the formation of a very fine magnetic brush capable of producing high quality prints as shown in a previous study.[6] The magnetic roll was made of a sintered ferrite magnet and is 20 mm in diameter. Both insulating and conductive magnetic roll surfaces were investigated. A nickel plating surface treatment was used to make the roll

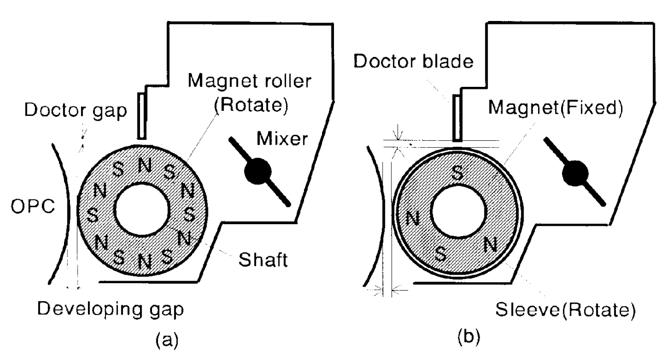

Figure 1. Developer units: (a) sleeveless, (b) with sleeve.

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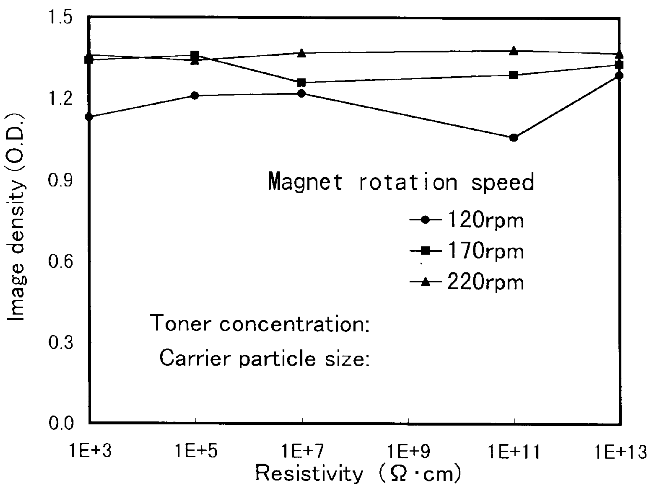

Figure 2. Change in image density with resistivity of carriers.

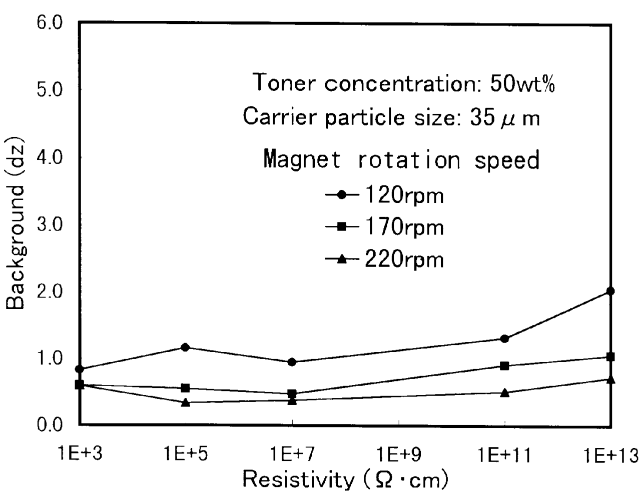

Figure 3. Change in background with resistivity of carriers.

surface conductive. The doctor gap and the developing gap were fixed at 0.3 and 0.4 mm, respectively.

Developers. To evaluate the developing characteristics of the new unit, mixtures of magnetic toner and iron carriers with various electrical resistivity and particle size were used. The toner consisted of polystyrene-acrylic copolymer, magnetite powder, polypropyren, and a charge control agent, and had an average particle diameter of 10μm. The carriers were made of polymer-coated iron powder and had irregular shapes. The electrical resistivities of the carriers were changed from 10^3 to 10^{13} Ω · cm by changing polymer coatings. The average particle sizes of the carriers were varied from 18 to 120 μm. The developers were prepared by mixing the appropriate ratio of toner and carrier in a polymer vessel to produce toner concentrations ranging from 10 to 100%.

System Layout. The developer unit of a conventional laser beam printer was replaced with the sleeveless developing unit to print out images for evaluation of the new unit. The printer was A4 size and equipped with an organic photoreceptor (OPC), with a peripheral speed of 25

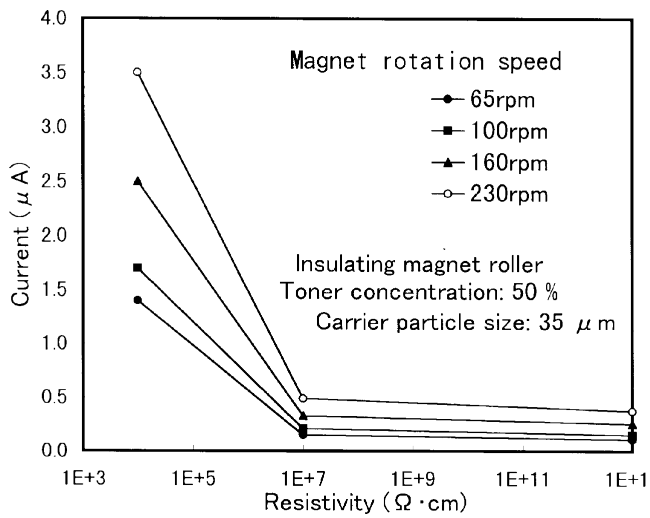

Figure 4. Change in current flowing between the doctor blade and photoconductor with resistivity of carriers.

mm/s. The image density of printed images was measured with a reflecting densitometer (Macbeth: RD-914). The background density was measured using a color difference computer. The current density flowing between the doctor blade of the developer unit and the photoreceptor was measured by replacing the photoreceptor with an aluminum drum of the same size. The system layout was used to investigate factors influencing printed images. In particular, the effects of carrier resistivity and particle size, toner concentration and rotational speed of the magnetic roll were examined.

Results and Discussion

Influence of Resistivity of Carriers. Figure 2 shows changes in image density with resistivity of the carriers for three choices of the magnet roll speed. Image density was almost independent of the resistivities of the carriers. Lower speed of the magnet roll gave lower image density, which may be attributable to the reduced rate of toner being conveyed to the developing area by the magnet roller. We predicted that image density would decrease with increase in the carrier resistivity due to an electrode effect, however, it was almost independent of the carrier resistivity. This result indicates that charged toner particles transfer from the carrier surface to the aluminium roll. This phenomenon will be discussed later in detail.

Figure 3 shows changes in background with resistivity of the carrier for three choices of magnet roll speed. The background gradually increased with an increase in resistivity of the carrier. This indicates that the carrier works somewhat as a developing electrode at lower resistivity. Lower rotational speeds of the magnetic roll produced a slightly higher background. The region with 10^5 to 10^7 in carrier resistivity and 170 to 220 rpm rotation speed is within our specification (background < 0.5).

Figure 4 shows the current flowing between the doctor blade and the photoconductor during the developing process as a function of carrier resistivity. The bias voltage of –600 V was applied to the doctor blade for these measurements. Carriers with resistivities larger than 10^7 Ω • cm showed small currents, while carriers with lower resistivities showed higher currents. Based on Figs. 2 to 4, we conclude that the developing mechanism of the new

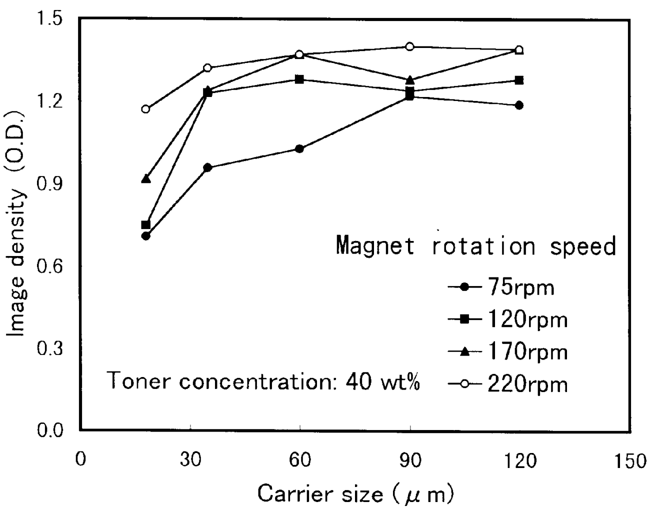

Figure 5. Change in image density with carrier size.

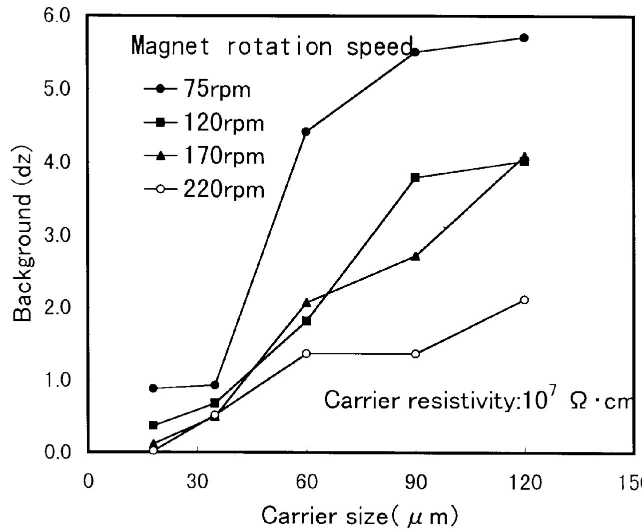

Figure 6. Change in background with carrier size with toner concentration at 40 wt%.

unit is not sensitive to the effect of the carrier electrode, but depends more strongly on electrostatic charging of toner by mixing with the carrier.

Influence of Particle Size of Carriers. Figure 5 shows changes in image density with carrier size for four rotation speeds of the magnet roll. The image density increased with an increase in both carrier particle size and in rotation speed of the magnet roll. The increase due to carrier size can be explained by higher magnetic brush of the larger carrier, and the increase due to rotation speed by increased rate of toner conveyed to the developing area. Carriers larger than 35 μm gave sufficient image density at rotation speeds of 170 and 220 rpm.

Figure 6 shows changes in background with carrier size for four rotation speeds of the magnet roll at a fixed toner concentration of 40%. Small carriers gave good results, but the background increased rapidly beyond the carrier size of 60 μm. The increase in background is consistent with insufficient charging of toner by larger carriers with smaller specific surface area. Lower rotational speeds also produced higher background, which may again be attributable to small charge-to-mass ratio of the toner. These results indicate that strong agitation of developers and sufficient surface area of carriers are necessary for sufficient charging of toners in this developing system as in most conventional ones. Figures 5 and 6 show that the carrier with average particle size of 35 μm gives the best image at rotation speed of 220 rpm, which means sufficient image density and fairly good background is available. Note that larger carriers are also available for lower toner concentrations of developers.

Influence of Toner Concentration. Figure 7 shows the electric current flowing between the doctor blade and the aluminum drum as a function of the toner concentration of developers for several choices of rotation speed of the magnet roll. The resistivity of the carrier of the developers was $1 \times 10^7\ \Omega \cdot cm$. Because both the magnet roll and toner were insulating, the current was very small, regardless of the toner concentration, even though the resistivity of the carrier was moderate. The current is considered to consist of mostly transport of charged toner particles from the carrier surface to the aluminum drum and partially conducting current through the carrier chain. Electric breakdown occurred between the tip of the magnetic brush and the aluminum drum when the toner concentration of the developer was less than 30%. In addition, development of carrier particles onto the aluminum drum occurred at toner concentration of less than 20%. The current was extremely small at toner concentration of 100% (carrier free), because the height of the magnetic brush was very small and the tip of the brush was not in contact with the aluminum drum.

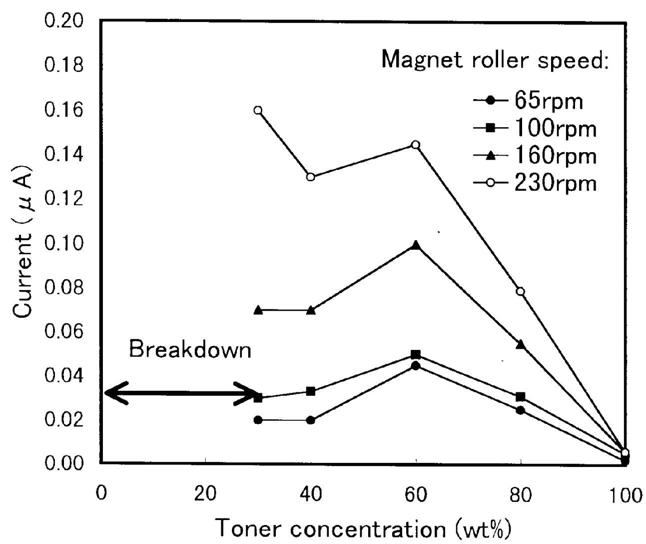

Figure 7. Electric current flowing between the doctor blade and the photoconductor as a function of toner concentration with an insulating magnetic roll and carrier resistivity at $10^7\ \Omega \cdot cm$.

Figure 8 shows image density and background as a function of toner concentration for the new developer system. The image density was sufficient at toner concentrations of greater than 30%. But, the background was within specification under 80 wt% of toner concentration. The breakdown phenomena described in Fig. 7 is concurrent with decrease image density in might because the breakdown decreases surface potential of the photoconductor.

Comparison of Insulating and Conducting Magnet Rollers. A conductive nickel coating was applied to the insulating magnet roll to improve the developing performance. Figure 9 shows currents flowing between the

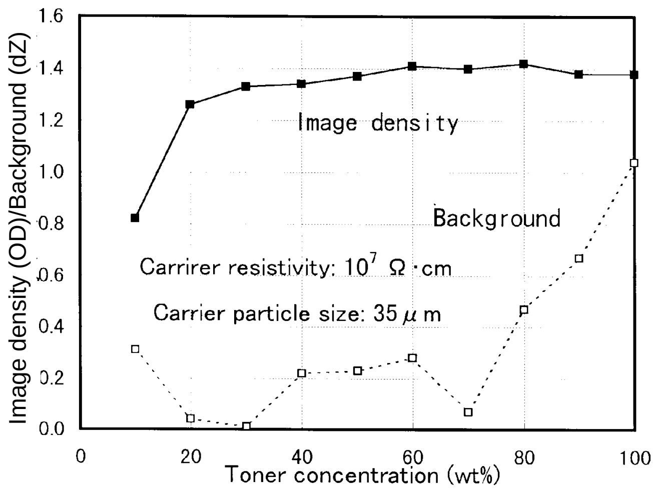

Figure 8. Image density and background as a function of toner concentration for a magnetic roll rotational speed of 230 rpm.

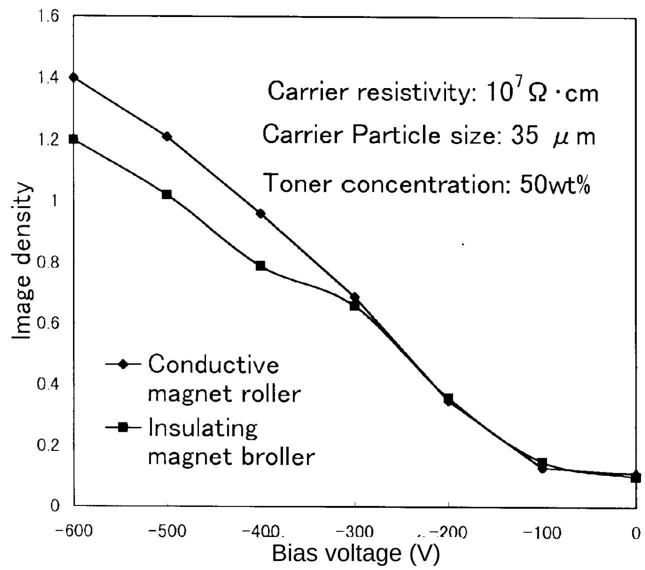

Figure 10. Change in image density with bias voltage and carrier size with magnetic roll speed at 230 rpm.

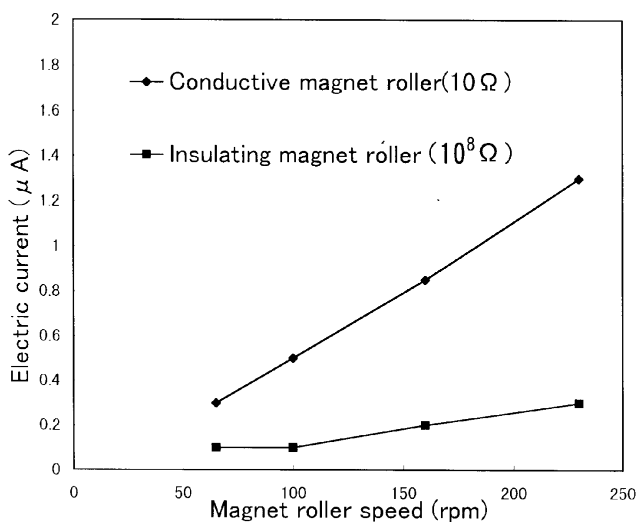

Figure 9. Electric current flowing between the doctor blade and the aluminum roll receiver as a function of magnetic roll speed for the insulating and conductive magnet rolls. Carrier resistivity was 10^7 Ω · cm and carrier particle size was 35 μm.

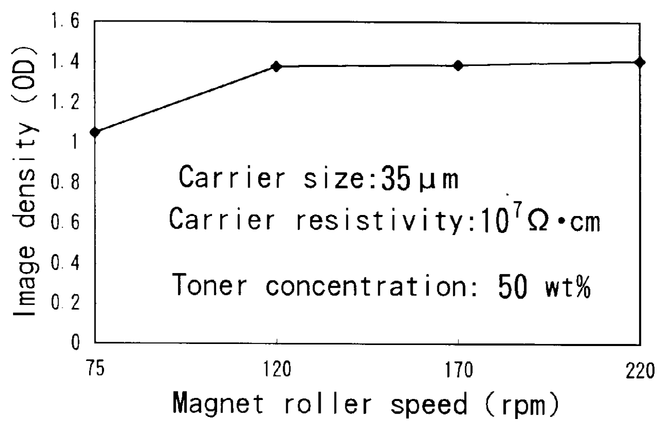

Figure 11. Change in image density as a function of magnetic roll speed for an insulating magnetic roll without a sleeve.

doctor blade and the aluminum drum as a function of rotation speed for the insulating and conducting magnet rolls. The current in the conducting surface-treated roller was about four times larger than that in the insulating one. The conductive surface treatment effectively increased the image density by about 1.2 times for bias voltages between –600 and –400 V, as shown in Fig. 10.

Optimum Developing Condition and Print Sample. Figure 11 shows image density as a function of magnet roll speed at optimum developing condition. At a photoreceptor speed of 25 mm/s, the optimum developing conditions use a carrier size of 35 μm and a toner concentration between 30 to 80 wt%. Higher magnetic roll speeds gave higher image densities, and sufficient image densities were available for speeds larger than 120 rpm.

A typical print image obtained by using the new sleeveless developer unit is given in Fig. 12. The black density is sufficiently high at about 1.4 OD and the background is within our specifications. The letter edge is as sharp and fog-free as conventional commercial printers.

Conclusion

The performance of a new electrophotographic developing system, which features a 32-pole sleeveless magnetic roll, was studied. Factors and developing conditions influencing image quality were examined. The best print image was obtained by using a carrier 35 μm in diameter. The resistivity of carriers did not influence the image density even if the electric current flowing between the doctor blade and the photoconductor depended strongly on carrier resistivity. The larger carriers gave higher image densities and worse background. Higher toner concentrations gave lower electric currents, but sufficient image density and low background were available at toner concentrations of less than 20 wt%. Higher magnetic roll speed gave higher image densities. Print samples generated by the system showed that a high pole frequency, sleeveless magnetic roll is a viable option for low cost printers.

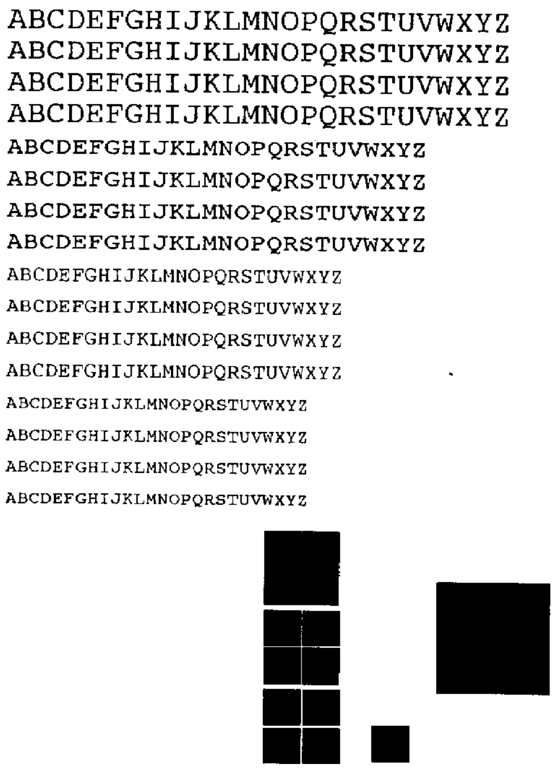

Figure 12. A print sample by the sleeveless developer unit produced using an insulating magnetic roll.

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