Development System by Toner Transportation Using Traveling Wave Electric Field

Katsumi Adachi, Shinji Yamana, and Tadashi Nakamura, Document Products Development Center, Digital Document Systems Group, Sharp Corporation, Yamatokoriyama, Nara, Japan

Abstract

We report on a development system by toner transportation using traveling wave electric field as a new non-contact development system for high-quality images. Toner is carried in a cloud-like state at high speed, but the toner gradually adheres to the surface of a FPC (used as toner conveyer), and the FPC is charged up as a result of contact with the toner. To solve this problem, we developed a new structure in which the FPC surface is covered by a thin, high-resistivity rotating belt. With this structure, it continuously removes the adhering toner and electrostatic charge. As a result, stable toner transportation is achieved without above-mentioned problems. By using this non-contact development system, we have achieved high quality image reproduction, resolving a closely arranged dot pattern of 1 by 1 to isolated 1200 dpi dot pattern.

Introduction

In recent years, various approaches have been used to improve the quality of images produced by electrophotographic process. Methods that have been investigated include reducing the toner particle size in order to reduce the amount of developing toner on the photoconductor and form a thin-layer toner image,[1] and increasing image resolution.

Issues with conventional development methods corresponding to these recent trends include toner sticking on the regulating blade as a result of decreased layer thickness of the toner layer on the developing roller.

Problems with increasing resolution, hindering the formation of small dots, include factors such as the scratching and dispersion action resulting from contact between the toner layer or magnetic brushes and the photoconductor, and changes in rotational condition resulting from fluctuations in the drive load of the developing roller.

Focusing on these points, we have investigated a developing system that uses traveling wave toner transportation,[2-5] and the application of this system to electrophotographic devices.

The Principles and Objectives of This System

Figure 1 shows a schematic diagram of the traveling wave toner transportation system used in this study. The electrode array that generates the traveling wave electric field is part of a FPC (flexible printed circuit) structure in which electrodes arranged in parallel at a fixed interval are sandwiched between sheets of poly-imide film, as shown in Fig. 1-(a). A traveling wave electric field is generated by applying four-phase alternating voltage to the FPC, as shown in Fig. 1-(b). With each change in the applied voltage on each electrode, an electric field is generated that moves the toner in a specific direction between adjacent electrodes; the toner moves to each electrode gap in order, and the forming a cloud state as it is transported.[2-4]

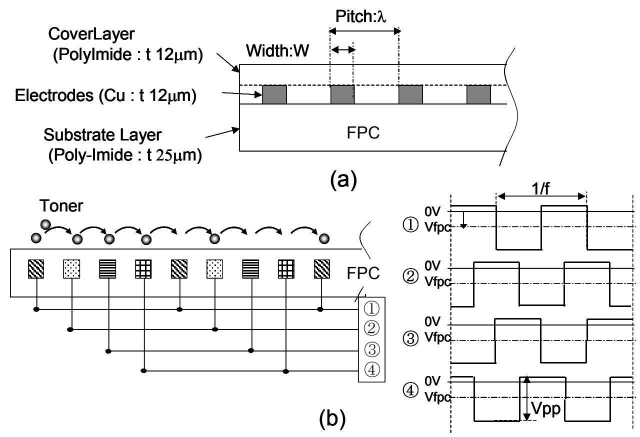


Figure 1. Schematic diagram of traveling wave toner transportation system

Figure 2 shows the experimental apparatus used in this study. Based on this diagram, we shall explain the apparatus operation when traveling wave toner transportation is applied to a development system for electrophotography, and shall explain the objectives of such application.

First, the toner supply roller supplies the toner onto the FPC. The amount of the supplied toner is adjusted by the amount of toner on the toner supply roller, the rotating speed of the roller, etc., to supply the amount needed by the developing process for each unit of time. The action of the traveling wave electric field causes the toner supplied onto the FPC to form a cloud-like state, and this toner is transported at high speed to the developing area. In other words, the required amount of toner for each unit of time passes through the developing area as a flow of toner with a low spatial density.

Accordingly, although a comparatively thick toner layer is supplied at low speed during the toner supply process, a thin toner image is formed during the development process due to the aforementioned action of the traveling wave toner transportation. This process alleviates the conventional restrictions of thin toner layer formation on the developing roller by mechanical means, and the restrictions of high-speed rotational drive. The toner in the cloud-like state is also highly responsive to minute latent images on the photoconductor, so this process is expected to yield high-resolution development performance. We therefore studied the utilization of this action as a means of resolving the aforementioned problems.

Toner Transportation Performance

First, we studied factors related to toner transportation performance. In this section, we report on the results of our study of three important functions related to toner transportation in an electrophotographic developing unit – 1)transportation stability, 2)toner supply capacity, and 3)transportation uniformity.

Transportation Stability

FPC Charge-up and Toner Adhesion

Figure 2 shows the experimental apparatus used in the study, and Table 1 shows the experimental conditions. The supply of toner onto the FPC is done using a modified non-magnetic single-component development apparatus (Ricoh, NX1000) market product; the electrically charged toner on the developing roller is supplied directly onto the FPC by the electric field between the developing roller and the FPC, and the toner that has been moved onto the FPC is then transported by the traveling wave electric field.

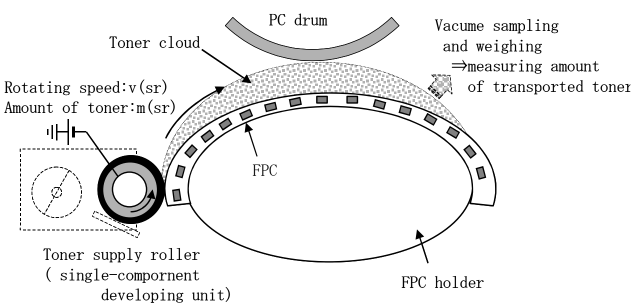


Figure 2. Schematic diagram of experimental system

It has been observed that the toner moves on the FPC in a cloud state at a speed of greater than several hundred mm/s (not shown due to limited space). However, as the transportation of toner continues, the condition of toner transportation becomes unstable and the toner gradually begins to adhere to the entire FPC surface.

Figure 3-(a) shows the changes in FPC surface potential with respect to the accumulation of transported toner. As the transported toner increases, it is recognized that the surface potential of the FPC rises. With this method, because the FPC itself acts as the developing electrode in the developing area, and the electric field distribution on the FPC surface affects the characteristics of toner transportation, the charge-up of the FPC becomes a factor causing variations in the development characteristics and transportation characteristics of the toner. It is clear that the degree charge-up on the FPC also depends on the toner used, and therefore, the charge resulting from the contact between the FPC surface layer and the toner during the toner transportation process is thought to be the primary reason.

Table 1: Experimental Condition

Traveling Wave				
Pitch λ [μm]	127	254	380	508
Width W [μm]	45	64	127	127
Vpp [V]	400	900	1300	1900
Frequency [Hz]	2000	1000	750	500
Wave form	Rectangle (Duty 50%, phase-difference π/2)			
Film or Belt				
Thickness		30 [μm]		
Material		Poly-imide + Carbon		
Toner Supply				
Without belt	M(sr)	≒ 8 × E-3 [kg/m2]		
	V(sr)	0.11 [m/s]		
With belt	M(blt)	0.8 ~ 1.5 × 1E-2 [kg/m2]		
	V(blt)	3 ~ 6 × 1E-2 [m/s]		
Toner				
Material	Non-conductive non-magnetic toner			
Diameter	7 [μm]			
q/m	-1.4 ~ 2 × E-2 [C/kg]			

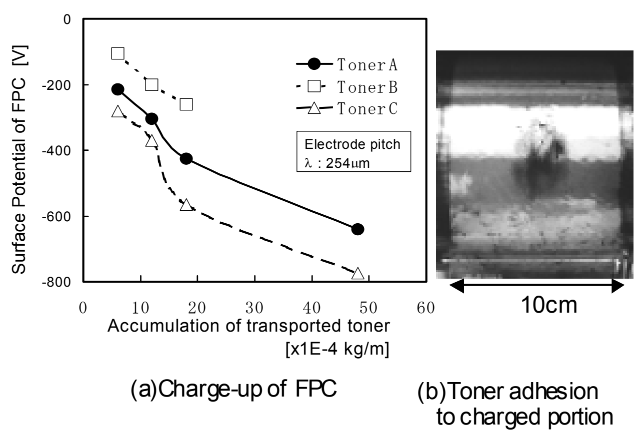


Figure 3. Charge-up and Toner adhesion of FPC

Figure 3-(b) shows the condition of toner adhesion when toner is transported after a charge is forcibly created at the center of the FPC surface. The toner adheres only to the charged area, and it is recognized that the toner adhesion is also related to the FPC charge up.

Discharge Effect and Transportation Characteristics with a High-Resistance Layer

A high-resistance film layer for discharging on the FPC surface was placed on the FPC surface of the experimental apparatus shown in Fig. 2, and we verified the discharge effects of the high-resistance layer.

Figure 4 shows the changes of film surface potential with respect to the accumulation of transported toner, taking the volume resistivity ρ as a parameter. The film layer thickness is approximately 30 μm, and the volume resistivity is measured at an applied voltage of 100 V. A large discharge effect is achieved when the film resistivity is 10^{12} Ωcm or less.

Next, we examined the influence of the time constant of the high-resistance film layer on toner transportation characteristic. Figure 5 shows the correlation between the frequency of traveling wave and amount of transported toner at an electrode pitch of 254 μm, taking film resistivity as a parameter. The amount of transported toner was measured by using suction to collect the toner that has been transported to the end of the FPC, and from the weighed value, the amount of transported toner for each unit width and time unit was measured.

Almost no toner transportation occurred at the film resistivity of 10^{9} Ωcm or lower, but transportation is possible at a film resistivity of 10^{10} Ωcm or higher. Amount of transported toner reaches a peak at a frequency of near 1 KHz, and we have verified that there is an optimum frequency range at which the toner follows the phase changes of the traveling wave.[2-4] At a film layer resistance of 10^{10} Ωcm or higher, the peak transported amount was almost the same, but as resistance decreased, transportation performance decreased in lower frequency range. Accordingly, we have verified that it is necessary to more carefully select a suitable frequency of traveling wave when using a high-resistance layer for discharging.

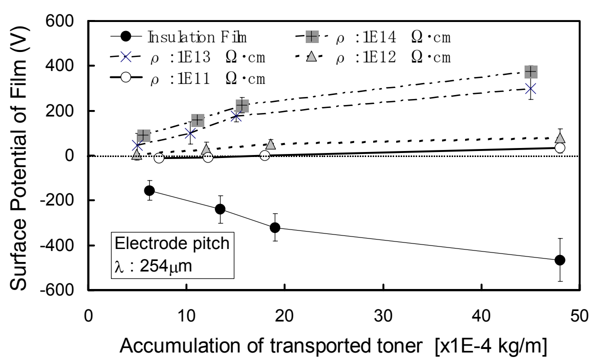


Figure 4. Discharge effect by High-resistivity Film

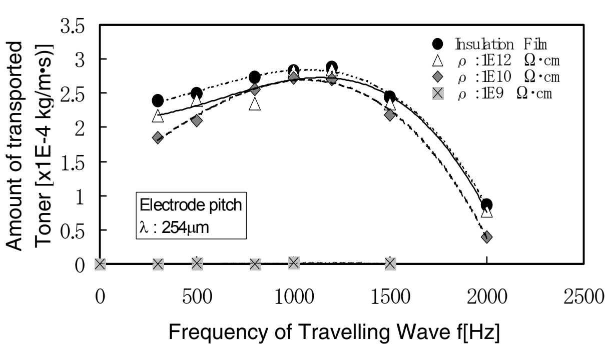


Figure 5. Effect of High-resistivity Film on toner transportation

Belt-covered System

With even longer use, however, more toner gradually adheres to the surface, and it is clear that continuous use is difficult. Thus, we investigated a toner transportation system in which the FPC surface is covered by a thin, high resistivity rotating belt, as shown in Fig. 6.

As a simple explanation of the operation of the system -- first, a prescribed toner layer is formed on the belt unit. The amount of toner supplied to the developing process is controlled by the amount of toner on the belt and the belt rotating speed. The toner layer on the belt moves to the FPC unit by the belt rotation, and the toner is conducted to the development area by the traveling wave toner transportation. The unused toner in the developing process is held again by the belt in areas where no traveling wave electric field is generated, and after that, the unused toner on the belt is eliminated with the belt cleaning unit, and further the belt itself is electrically discharged with the discharging unit.

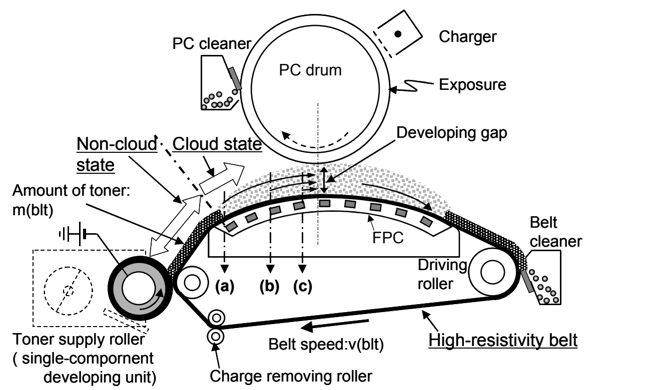


Figure 6. Schematic diagram of Belt-covered System

We verified that, in this system, the continuous cleaning and discharging of the belt surface is possible, the abovementioned toner adhesion phenomenon is solved, and the stable traveling wave toner transportation continues.

Toner Transportation Capacity

Figure 7 shows the changes in toner transportation capacity with respect to the electric pitch of the FPC.

The details of experimental conditions are shown in Table 1. The toner transportation capacity is compared under the condition of frequencies which give the maximum amount of transported toner at each electrode pitch. The evaluation of the amount of transported toner with the belt-covered system was conducted using the following method. The amount of toner on the belt (m(blt), 0.8 to 1.5 × 10^{-4} kg/m^2) and belt rotation speed (v(blt), 3 to 6 × 10^{-2} m/s) were varied to adjust the amount of toner supply. The conditions under which almost no toner remained on the belt were taken as providing the maximum amount of transported toner.

For example, with the printing conditions of a process speed of 0.1 m/s and a developing toner volume of 0.4 × 10^{-2} kg/m^2, a toner supply volume of 4×10^{-4} kg/(m-s) is necessary. This requirement could be satisfied with the condition of an electrode pitch λ of 254 μm using the belt-covered system.

Further widening of the electrode pitch increases the toner transportation performance, and we have verified that this toner transportation capacity can be utilized with electrophotographic devices.

We also tested a belt-less system, using the method described in preceding section 3-1, to make measurements with the toner supply conditions set so that a toner volume of $9 \text{ X } 10^{-4}$ kg/(m-s) pass over the FPC surface.

In belt-less system, ability of toner transportation is lower than the belt-covered system. This is because when the toner is applied to the FPC surface, if a large supply electric field is applied in a toner supply area, the supplied electric field blocks toner transportation electric field.

We have verified that a characteristic of the belt-covered system is that the toner supply and toner transportation functions are separate, allowing for effective transportation performance based on the travel wave electric field.

Transportation Uniformity

Next, we examined the uniformity of toner transportation. The evaluation method is that, using the experimental apparatus shown in Fig. 6, a half-tone image is created with bias development by applying voltage directly to the conductive substrate of the photoconductor drum, and the uniformity of toner transportation was then evaluated from the condition of the image.

Figure 8 (a) to (c) show images developed when the length of transportation to the development area was varied by moving the starting position of toner transportation (via a traveling wave electric field), in order, from point (a) to point (c) shown in Fig. 6. The lengths of transportation from points (a), (b) and (c) to the development area were 30 mm, 8 mm and approximately 0 mm, respectively. As the transportation length decreases, the striped pattern gradually becomes thinner, and when toner transportation begins near the development area (condition (c)), the striped pattern disappears almost completely. This pattern is thought to be due to minute roughness or localized electric charges on the toner transportation surface causing uneven transportation electric fields; this results in a slight deflection of the toner flow, and as this toner flow deflection progresses, the flow of toner repeatedly breaks up and converges, forming large striped patches.[5]

A short transportation length nearly eliminates the striped pattern, but the type of patchy unevenness shown in Fig. 8-(c) still remains. This is thought to be due to variability in toner behavior at the start of transportation. The factors cited as causing this variability is the non-uniformity of adhesion force between toner layer and belt, or that of the toner layer itself. Figure 9 shows a system in which a two-phase standing wave electric field with a 180° phase difference is generated prior to the start of toner transportation via a traveling wave electric field, converting the toner layer to a cloud-like state prior to transportation (a "pre-cloud") in order to align toner behavior at the start of traveling wave transportation. The electrode pitch and applied voltage in the pre-cloud area are the same as those used to generate the traveling wave.

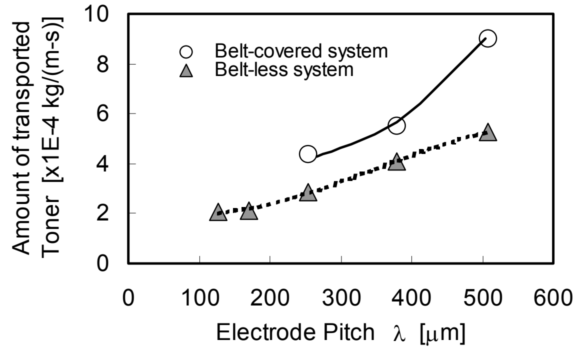


Figure 7. Capacity of toner transportation

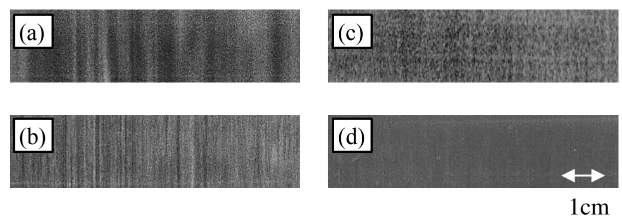


Figure 8. Uniformity of toner transportation, (a)-(c): Effect of transportation length, (d) :Effect of Pre-cloud and uniformed toner layer

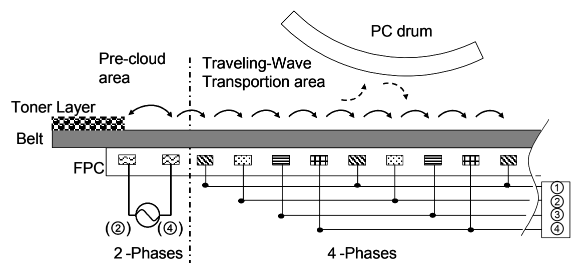


Figure 9. Pre-cloud system

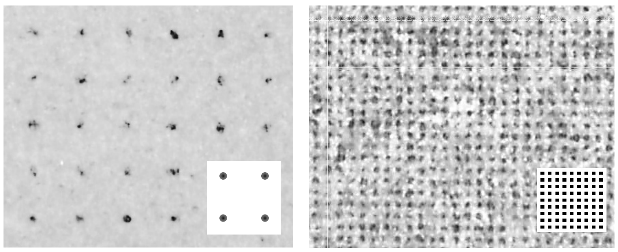
Improvements were also made to the surface accuracy of the toner supply roller and to the toner layer formation conditions in order to improve the uniformity of the toner layer on the belt. As a result, it was possible to eliminate the patchy unevenness, as shown in Fig. 8-(d).

Accordingly, we have verified that the belt-covered system is also effective in unifying toner transportation because this type of configuration makes it possible to set a suitable transportation length and suitable conditions for the start of transportation.

Non-Contact Development Performance

Resolution Performance

Based on the results described above, we examined non-contact development using the experimental apparatus shown in Fig. 6 in order to study resolution performance. The exposure apparatus used was a 1200 dpi LSU of MFP market product (Sharp, AR255P). Figure 10 shows enlargements of 1200-dpi dot images developed on the photoconductor. The conditions used for developing were as follows – surface potential of the photoconductor: -800 V, developing bias (central value V (fpc) of the traveling wave voltage): -500 V, developing gap: 0.25 mm, photoconductor thickness: 22 μm, process speed (from LSU specifications): 61 mm/sec. The toner transportation volume was set at 3 X 10^{-4} kg/(m-s) using a FPC with an electrode pitch of 254 μm.



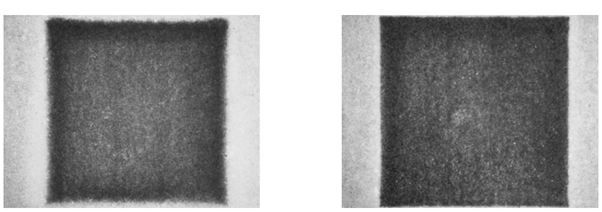
1by7 isolated dot 1by1 dot

Figure 10. Macrophotograph of 1200dpi dot

Two types of dot arrangements are possible to develop with this system – a "1 by 7" isolated dot arrangement in which each dot is arranged at 7-dot intervals, and a "1 by 1" high-density dot arrangement. In general, as the resolution of the latent image pattern is increased, the electric potential difference between the image area and the non-image area decreases.[6] Because the toner is converted to a cloud-like state, however, it is thought that with this system, the toner can, with a high degree of sensitivity, follow even the changes in electric potential distribution caused by minute dots.

Edge Deletion

The last matter we shall discuss is a problem with this system. It has been reported that with non-contact development, defects can occur easily at the image edges.[7] Figure 11 shows the condition of the developed image of a 7 mm square patch. Under the condition that the developing gap is 1 mm, the defect (edge deletion) occurs at the image edges. When the developing gap is reduced to 0.25 mm, this phenomenon almost completely disappears.



Developing Gap:1mm Developing gap:0.25mm

Figure 11. Edge deletion

Figure 12 shows development curves of electrode pitches of 254 μm and 508 μm at a developing gap of 0.25 mm. With a narrow developing gap, widening the electrode pitch increases the electric potential difference that suppresses toner adhesion on non-image areas (background noise), so the non-image area electric potential must be set to a high value. In order to increase toner transportation performance for high-speed printing, it is necessary to increase the electrode pitch, but the edge deletion described above also tends to progress when the surface potential of the photoconductor is increased in non-image areas. As such, we have verified that one issue with this method is achieving high-speed printing while eliminating the problem of edge deletion.

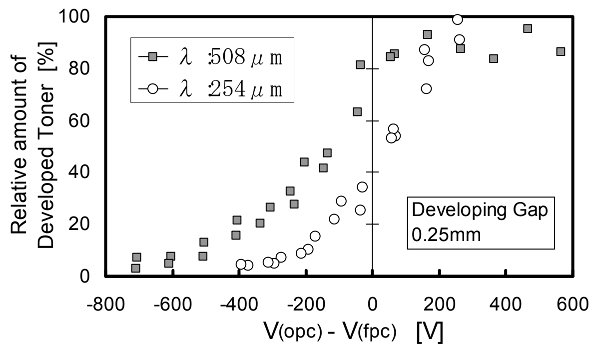


Figure 12. Development Curve (Dependence of λ)

Conclusion

We have studied the application, to electrophotographic equipment, of a development system utilizing the principle of toner transportation via a traveling wave electric field. The results of this study have verified that the use of a belt-covered system achieves more stable and uniform toner transportation, and have verified the high-resolution image developing performance of non-contact development. Conversely, the study has also verified the problem of eliminating edge deletion while achieving high-speed printing.

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Author Biography

Katsumi Adachi received B.S. degree in Industrial Chemistry from Institute Technology of Kyoto in 1990. After graduation, he joined Sharp Corporation in 1990. He has been engaged in a research and development of copiers and printers. His current work is to research a development system. He is a member of the Imaging Society of Japan.