New Effect of AC High Field on Toner Transfer

Shinji AOKI, Haruo IIMURA, Yasuhiko OGINO, Keigo NAKAMURA, Ichiro MAEDA, Naomi SUGIMOTO and Shinya TANAKA
Imaging Engine Development Division, Ricoh Company, Ltd.

Abstract

The effect of ac high fields on toner transfer in electrophotography has been studied. It has been revealed that the high ac components generate the reciprocating motions of toner particles in recessed portions of papers, and reduce the toner adhesions by repeatedly providing the physical and the electrical interactions among toner particles. Therefore, since toner particles can be transferred onto papers by low dc components, uniform images are realized even on heavily textured papers without discharge generation.

Introduction

In electrophotography, the main driving force for transferring toner onto paper is the electrostatic force, and commonly, dc fields as large as the Paschen limit are formed in the transfer regions.

By using the simple dc fields, although obtaining uniform images is not difficult on plain papers, that is very tough on textured papers. This is because, in the case of the secondary transfer processes with intermediate transfer belts (ITBs), there are air gaps between toner particles on the ITBs and the surface at the recessed portions of the papers, and therefore in the areas, the external electric fields are weak, and the non-electrostatic adhesion forces between the toner particles and the papers do not act on the toner particles on the ITBs. In other words, in order to improve the transfer ability at the recessed portions, reducing air gaps between the toner particles on the ITBs and the papers, or reducing adhesion forces between the toner particles and the ITBs is necessary.

As a technique for reducing the air gaps at the recessed portions, the one using elastic rubber belts as ITBs is known [1,2]. The air gaps become small since the rubber layers deform to fit the paper surfaces. On the other hand, as a technique for reducing the adhesion forces, the one using clear toners is known [3]. A clear toner image is transferred onto an ITB in advance, and then color images are transferred onto the clear toner image. Since the adhesion forces between the color toner particles and the clear toner particles are smaller than those between the color toner particles and the ITB, more color toner particles are transferred onto the recessed portions. Although these techniques provide better transfer abilities at the recessed portions, they have some problems including the manufacturing costs or the printing cost due to the clear toner consumption.

And so we have tried to improve the transfer abilities at the recessed portions by controlling the electric field, and have developed a new transfer technique using ac high fields. The technique dramatically improves the transfer abilities at the recessed portions. By using the technique, uniform images are realized on textured papers even if they have over 100-μm height differences between the highest and lowest points of the surfaces.

In this paper, the characteristics of the technique using ac high fields are introduced and mechanisms of the improvement due to the technique are discussed.

Characteristics of the Toner Transfer Technique Using AC High Fields

In the technique using ac high fields, the voltages consisting of ac and dc components are applied to transfer members, such as the transfer rollers. The applied voltages have two main characteristics. The first characteristic is that the ac components have large amplitudes and cross 0 V. In the case the sine wave voltage is used as the ac component, the peak to peak voltage V_{p-p}, which is twice the amplitude, is set to 4 times larger than the absolute value of the dc component voltage V_{dc}. And the second characteristic is that the absolute value $|V_{dc}|$ in the technique is much smaller than the ones in the conventional technique using simple dc fields. That is, the point of the technique is forming ac high fields superimposed on dc low fields in the transfer regions effectively.

Figure 1 shows image samples printed out on a textured paper with an experimental printer employing an intermediate transfer system in which a polyimide belt is used as the ITB. The paper is LEATHAC 66 manufactured by Tokushu Paper Mfg. Co. Ltd, which has the ream weight of 260 kg and has about 160-μm height difference between the highest and lowest points of the surface. The image sample (a) is secondary transferred by using the technique using an ac high field, and the image samples (b), (c), and (d) are obtained by the conventional simple dc fields. In the case of the technique using the ac high field, a sine wave ac voltage having 7.2 kV_{p-p} with 1.2 kV_{dc} is applied to a transfer roller, and in the case of the conventional ones, 2.0, 3.0 and 4.0 kV_{dc} are applied to it (see Figure 2). In the technique using the ac high field, the V_{p-p} is set to 6 times larger than the $|V_{dc}|$, and the $|V_{dc}|$ is set to 40% of that in the best condition for the image (c) in the conventional technique. The uniformity of the image obtained by the technique using the ac high field is obviously much better than those obtained by the conventional technique using the simple dc fields.

In the following sections, mechanisms of the improvement of the transfer ability due to the technique using ac high fields are discussed focusing on the high ac components and the low dc components. And in the discussions, sine wave voltages are addressed as the ac components.

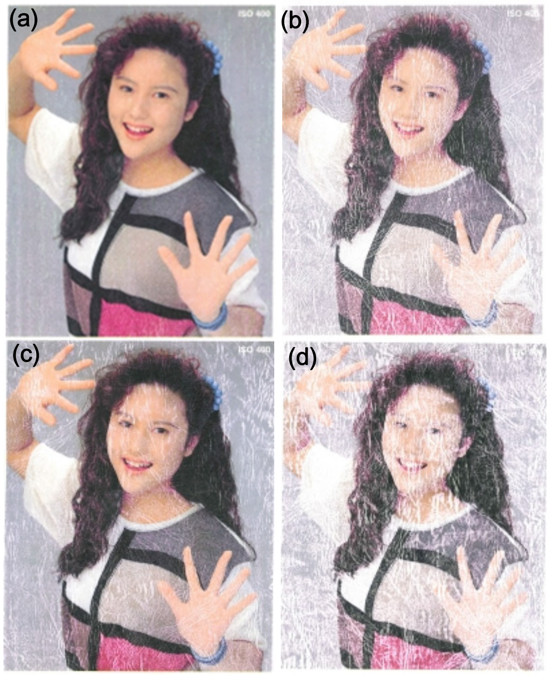

Figure 1*. Image samples printed out on the LEATHAC 66 (260 kg, A4 size) with an experimental printer. (a) is by an ac high field with 7.2 $kV_{p\text{-}p}$ plus 1.2 kV_{dc}, and (b),(c) and(d) are by simple dc fields with 2.0, 3.0 and 4.0 kV_{dc}.*

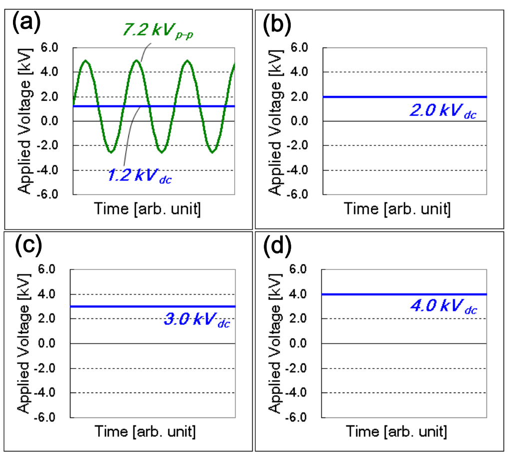

Figure 2*. Voltage wave forms used for the images (a), (b), (c) and (d) in Figure 1.*

The Effect of the High AC Components

The effect of the high ac components on the transfer abilities at the recessed portions has been studied by using model experimental apparatuses consisting of parallel plate electrodes.

Firstly, a transfer process of toner particles has been observed by using the model experimental apparatus shown in Figure 3. The toner particles developed on an indium tin oxide (ITO) electrode have been transferred onto the LEATHAC 66 by an ac high field, and the toner behavior in a recessed portion has been observed from the horizontal direction with a high speed camera. Incidentally, as shown in Figure 4, the transfer ability improvement due to the ac high field has been confirmed prospectively in the model experimental apparatus.

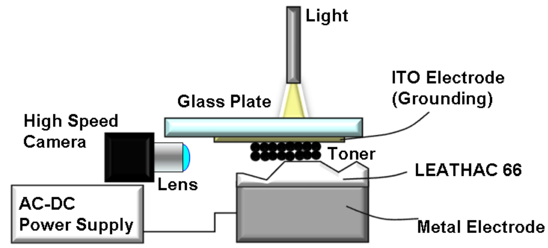

Figure 3*. A schematic diagram of the model experimental apparatus for the horizontal observation.*

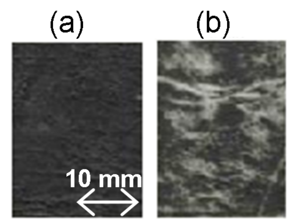

Figure 4*. Image samples printed out on the LEATHAC 66 (260 kg) with the model experimental apparatus. (a) is by an ac high field with 0.2 kV_{dc} plus 1.6 $kV_{p\text{-}p}$, and (b) is by a simple dc filed with 0.5 kV_{dc}.*

Figure 5 shows the motions of toner particles in the recessed portion. It is confirmed that the toner particles in the recessed portion are reciprocated by the ac component, and as the number of times of the reciprocating motion increases, the number of the reciprocating toner particles increases.

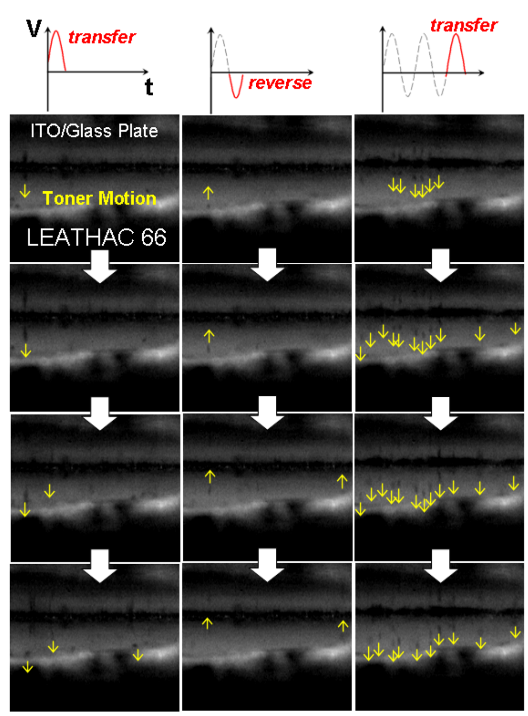

Figure 5*. Observed reciprocating motions of toner particles in a recessed portion of the LEATHAC 66 (260 kg).*

Furthermore, by using the model experimental apparatus shown in Figure 6, the reciprocating motions of the toner particles have been studied. The reciprocating motions have been generated between the electrodes by a high ac component, and have been observed from the vertical direction with a high speed camera, by varying the amount of developed toner on the ITO electrode as shown in Figure 7. The lens has been focused on the surface of the ITO electrode, therefore, observed toner particles are remaining or returned ones on the ITO electrode. And then, the ratios of the moving toner particles have been calculated from the observations, and effects of the amount of the developed toner and the number of times of the reciprocating motion to the ratio have been analyzed. However, since it is difficult to measure the developed and the reciprocating toner directly by weight, the area of the toner particles existing on the ITO electrode is estimated from the observations and is used as an alternative characteristic of the toner amount for the analysis.

The ratio of moving toner R_m, in units of percent, is calculated by Equation (1):

$$R_m = [(A_i - A_r) / A_i] \times 100, \quad (1)$$

where A_i is the total area of the toner, which is developed on the ITO electrode, and A_r is the one, which is remaining on the ITO electrode when the peak transfer field toward the metal electrode is formed in each ac cycle.

And the initial toner coverage on the ITO electrode θ_i, in units of percent, is calculated by Equation (2):

$$\theta_i = (A_i / A_o) \times 100, \quad (2)$$

where A_o is the area of the observed region.

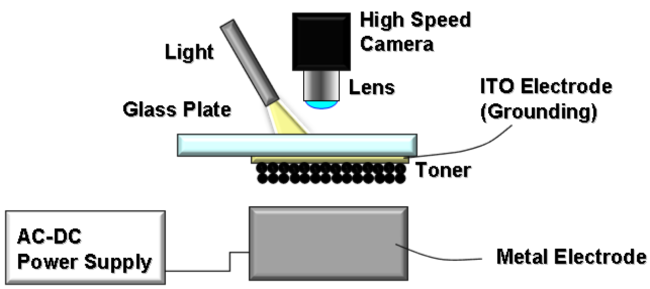

***Figure 6**. A schematic diagram of the model experimental apparatus for vertical observation.*

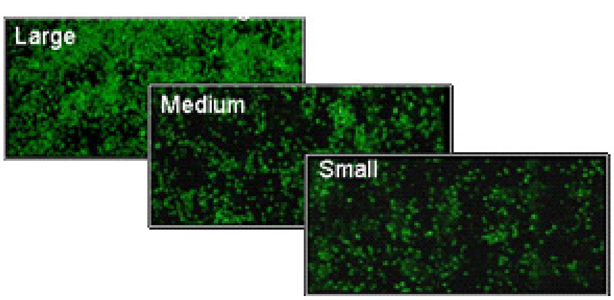

***Figure 7**. Initial developed toner images on the ITO electrode with different coverages.*

Figure 8 shows relationships between the ratio of moving toner and the number of times of the reciprocating motion. It is confirmed that as the number of times of the reciprocating motion increases, the ratios of the reciprocating toner particles increase, and that the lower initial toner coverage is, the lower the ratio becomes.

In the meantime, Figure 9 shows magnified views of toner particles in an observation. In the areas of (b) and (c), the returned toner particles due to an ac component flick the remaining ones, and lead them to transfer. On the other hand, in the area of (a), although the collision between the toner particles is not confirmed, it is suggested that the returned toner particle stimulates the remaining one to transfer by the Coulomb force. In other words, the reciprocating toner particles reduce the toner adhesions by the physical and the electrical interactions among toner particles. The reason why the ratio of moving toner decreases as the initial toner coverage decreases, as shown in Figure 8, is because the probability of the interactions decreases as the initial toner coverage decreases.

That is to say, the high ac components of the ac high fields generate the reciprocating motions of toner particles in recessed portions of papers, and reduce the toner adhesions by repeatedly providing the physical and the electrical interactions among toner particles. Therefore, it is suggested that as the number of times of the reciprocating motion increases, the number of the toner particles of which the adhesions are reduced increases.

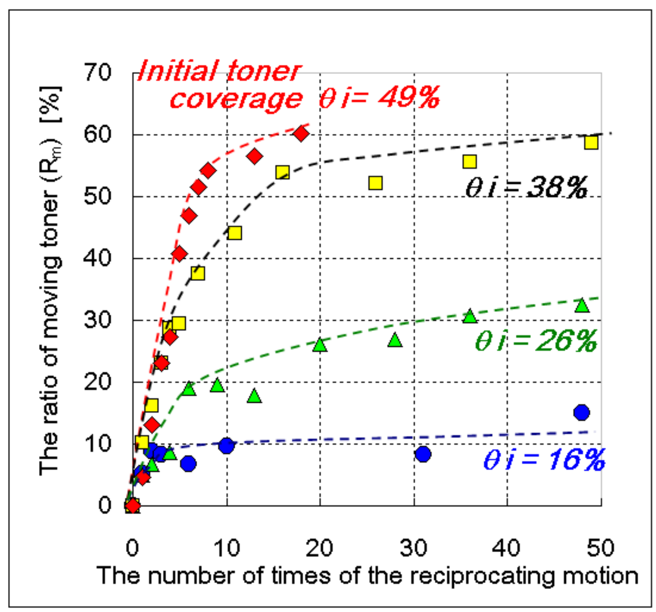

***Figure 8**. Relationships between the ratio of moving toner and the number of times of the reciprocating motion with various initial toner coverages.*

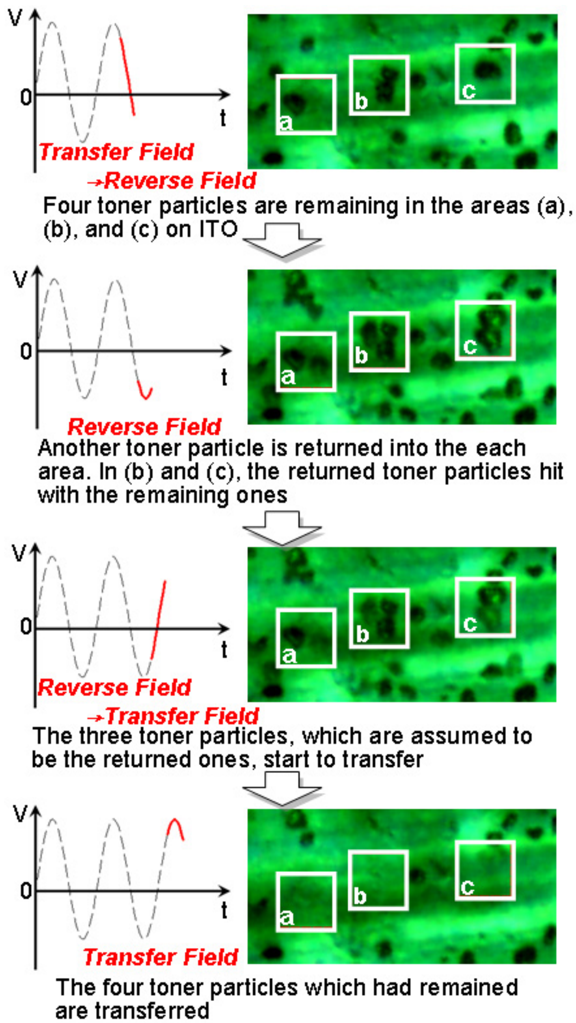

***Figure 9**. Observed toner interactions depending on a high ac component in the model experimental apparatus.*

The Effect of the Low DC Components

The dc components provide the electrostatic force for holding toner to transfer media. For example, in the case of the model experimental apparatus shown in Figure 6, the minimum dc component for transferring and holding a toner layer to the metal electrode in electrostatics, which is denoted as $V_{dc,min}$, is the reverse value of the surface potential of the toner layer on a grounding electrode. On the other hand, in order to obtain the effect of the high ac components with the reciprocating motions of toner particles, the transferred toner layer on the metal electrode must be returned to the ITO electrode, and the minimum voltage for returning the toner layer, which is denoted as $-V_r$, is equal to $-V_{dc,min}$. The graph (a) in Figure 10 shows a voltage wave form consisting of $V_{dc,min}$ as V_{dc} and $-V_{dc,min}$ as $-V_r$. In this case, the V_{p-p} of the wave form $V_{p-p,min}$ is expressed by Equation (3):

$$V_{p-p,min} = |V_{dc,min} - (-V_{dc,min})| \times 2 = 4|V_{dc,min}|. \quad (3)$$

As Equation (3) shows, in order to obtain the effect of the high ac components, the V_{p-p} must be set to 4 times larger than the $|V_{dc,min}|$. However, commonly the V_{dc} and the V_r are set to larger than $V_{dc,min}$ as shown in Figure 10 (b), since the transfer abilities may be insufficient in some areas on papers. And it should be noted here is that, since the peak voltage is equal to $|2V_{dc} + V_r|$, as the V_{dc} becomes higher, the peak voltage becomes higher. That is, suppressing the dc components is important for suppressing the peak voltages.

As a practical matter, it is confirmed that when the reciprocating motions of toner particles are generated by high V_{p-p} superimposed on high V_{dc}, white spots appear on transfer images at the recessed portions of the paper as shown Figure 11.

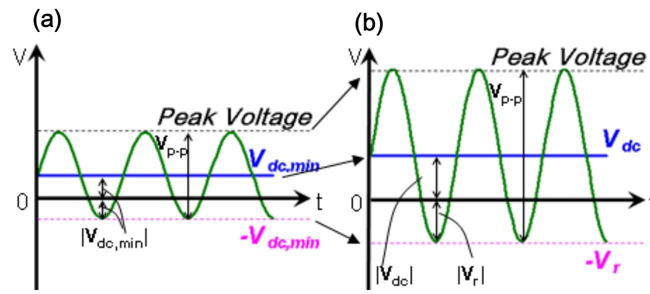

***Figure 10**. Relationship between V_{dc}, V_r and V_{p-p}.*

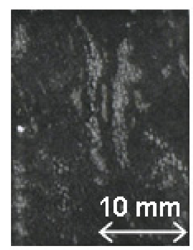

***Figure 11**. An Image sample printed out on the LEATHAC 66 (260 kg) with the model experimental apparatus with a voltage of a high V_{dc} superimposed on a high V_{p-p}.*

Figure 12 shows a model experimental apparatus for discharge observation with an image intensifier, and Figure 13 shows observed discharge on the LEATHAC 66 sandwiched between the ITO and the metal electrodes. In the case of a high ac component of 2.5 kV_{p-p}, spot discharges are observed at the recessed portions. And furthermore, it is clear that the spot discharges are the cause of the white spots on transfer images.

That is to say, suppressing the dc component is necessary for bringing out the effect of the high ac components without discharge generation.

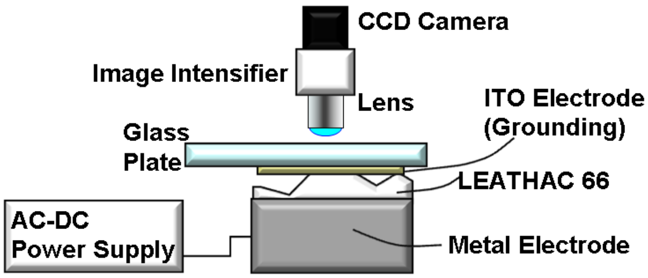

Figure 12. *A schematic diagram of the model experimental apparatus for discharge observation with an image intensifier.*

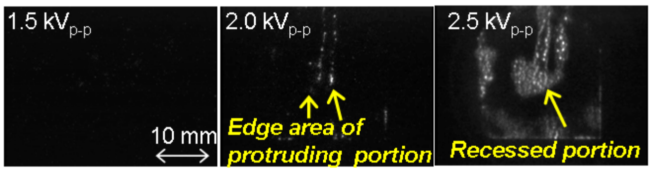

Figure 13. *Observed discharge on the LEATHAC 66 (260 kg) sandwiched between the ITO and the metal electrodes.*

In the meanwhile, as mentioned above, as the number of times of the reciprocating motion increases, the number of the toner particles of which the adhesions are reduced increases. Therefore, as the number of times of the reciprocating motion increases, lower dc component can be used, and as the result, uniform images are realized without discharge generation. However, it is to be noted that excess reciprocation for transferring toner using low dc components may cause toner scatterings, especially at recessed portions as shown in Figure 14, due to the Coulomb forces between toner particles and the collisions between toner particles and paper.

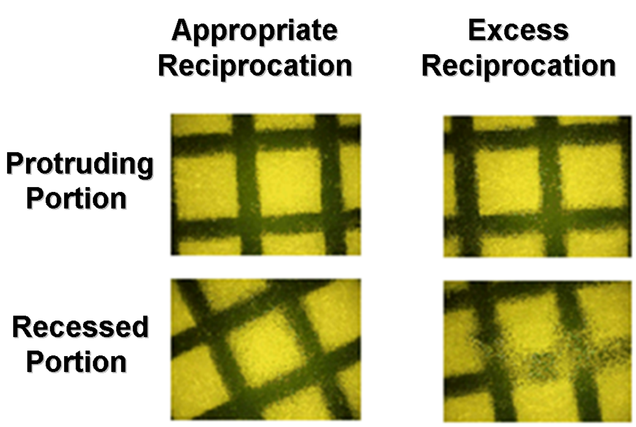

Figure 14. *Toner scatterings generated by the reciprocating motion of toner particles.*

Conclusions

The effect of ac high fields on toner transfer in electrophotography has been studied. It is clear that the high ac components generate the reciprocating motions of toner particles in recessed portions of papers, and reduce the toner adhesions by repeatedly providing the physical and the electrical interactions among toner particles. Therefore, since toner particles can be transferred onto papers by low dc component, uniform images are realized even on heavily textured papers without discharge generation.

Now further studies by using various bias waveforms are underway, and on the other hand, the transfer techniques using ac high fields have been applied to some production printers of RICOH as the name of the AC Transfer technology. The AC Transfer technology is used for the RICOH Pro C5110S/C5100S launched in June 2013.

RICOH Pro C5110S (http://www.ricoh.co.jp/).

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Author Biography

Shinji AOKI received his A. Eng. from Kobe City College of Technology (1993), his B. Eng. from Okayama University (1997), and his M. Eng. from Osaka University (1999) in applied chemistry. He worked for Kao from 1993 to 1995, and worked for Toshiba and Toshiba Tec from 1999 to 2003. He joined Ricoh in 2003, and has been engaged in R&D of electrophotography. He is a member of IS&T and ISJ.