

Numerical Simulation of Separating Discharge in the Belt Transfer System

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Abstract

The belt transfer system is one of the image transfer processes used in electrophotography.[1,2] In this process, paper clings to the electro-resistive belt, and is stably fed through the processor. However, electrical discharge may occur between the paper and the belt when the paper is separated from the belt under particular conditions. This discharge is named “separating discharge”. Since this discharge causes image degradation, it is important to make clear the separating discharge phenomenon. A model experiment is carried out in order to construct a simulating model of separating discharge and image degradation. A model, which generates separating discharge patterns on the backside of paper, is proposed and numerical simulation based on this model is carried out. This model shows the strong correlation between the sheet potential before separation (Vs) and the discharge. When Vs is low, local strong discharge occurs intermittently. On the other hand, the separating discharge becomes continuous and weak when Vs is high. Toner-movement due to discharge is also numerically simulated using discrete element method, and the result shows that the image degradation occurs at low Vs , whereas it does not occur at high Vs.

The Belt Transfer System

The belt transfer system is shown in Fig. 1. The paper is held on the electro-resistive belt and fed under the photoconductor. This system assures stable and fast paper feeding. Toner is transferred from the photoconductor to the paper at the nip between the photoconductor and the belt. Since a high voltage is applied to the back of the belt, a weak discharge occurs in the vicinity of the nip between the paper and the photoconductor, and charges the paper with the same polarity as the toner. Under high temperature and humidity, the charge on the paper flows away through the paper and the belt. When the temperature and the humidity are low, the paper resistance is so high that the charge remains on the paper. Thus discharge between the paper and the belt may occur when the charged paper is separated from the belt. This discharge, named “separating discharge”, may degrade the image that has not yet been fixed on the paper.

Objective

The objective is to simulate the image degradation due to separating discharge between the paper and the transfer belt using the model based on the experiment, so as to make a suggestion for preventing the image degradation in the belt transfer system.

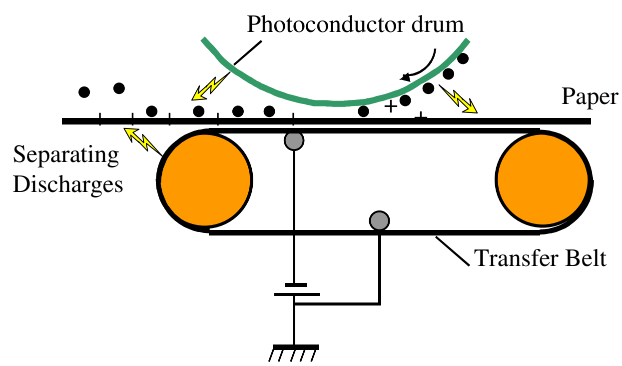


Figure 1. The schematic diagram of the belt transfer system

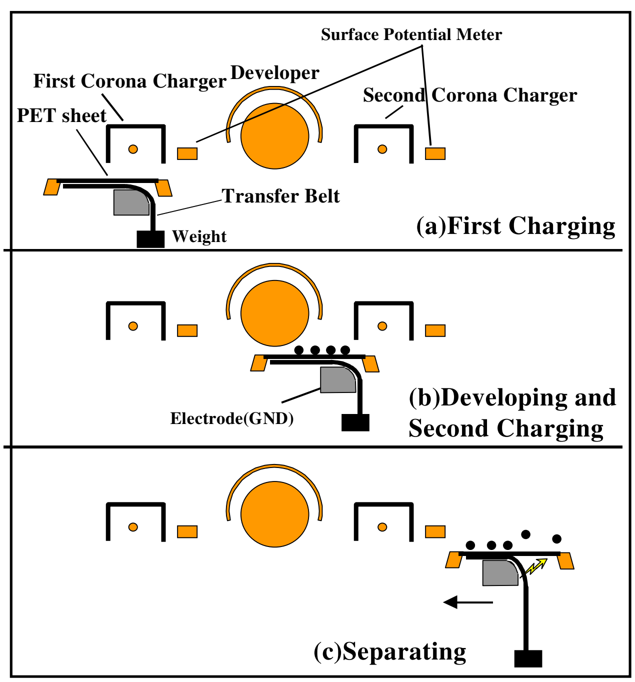
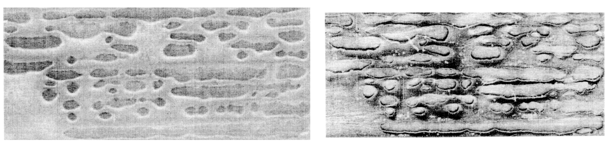


Figure 2. The sequence of the experiment

Model Experiment

In order to investigate the phenomena of the separating discharge, model experimental setup is constructed[3]. Figure 2 shows the sequence of the experiment. PET [poly(ethylene terephthalete)] sheet with 100 micron thickness is used instead of paper because it has stable resistance. A transfer belt is set under PET sheet after cleaning with alcohol. The back of the belt is grounded by the electrode. The first process of the experiment is charging the sheet by a corona charger as shown in Fig. 2(a). The second process of the experiment is development of the sheet by the developer and charging again by the second corona charger (Fig. 2(b)). The last process of the experiment is to slide the electrode and to separate the belt from the sheet (Fig. 2(c)). The sliding speed is 2.5[mm/s] and the sliding distance is 30[mm]. The experiments are carried out under the environmental conditions of 20[°C] and 10[%RH].



(a) Degraded image (image side) *(b) Discharge pattern (Backside)*

Figure 3. Agreement between degraded image and discharge pattern

Experimental Results

When the electrode is slid after forming the image on the sheet, the image degradation can be observed with the movement of the electrode as shown in Fig.3(a). Also the discharge pattern of the opposite surface is obtained by cascade development[4] after sliding the electrode, as shown in Fig. 3(b). The shape of the degraded image on the surface side of the PET sheet is in good agreement with the discharge pattern on the backside of the sheet. In order to confirm that the image degradation is due to separating discharge between the sheet and the belt, discharge observation is carried out. Figure 4 shows the schematic diagram of the experimental setup of the observation. As the transparent PET sheet without toner development is used, discharge light can be observed using image intensifier in a darkroom. An example of the observed light from the viewpoint above the sheet is shown in Fig. 5. The shape of the discharge light is in good agreement with that of the discharge pattern shown in Fig. 3. From these results, image degradation should be due to the separating discharge between the sheet and the belt.

Figure 6 shows the discharge pattern when the sheet is negatively charged before separation. The completely different shape is observed from Fig. 3(b). As the effect of the polarity on the discharge patterns is very similar to that on Lichtenberg's figures, surface discharge may be concerned with generating discharge patterns.

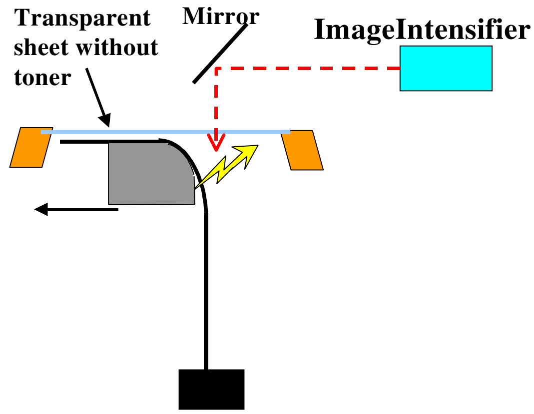


Figure 4. Experimental setup for the observation of light emission due to separating discharge

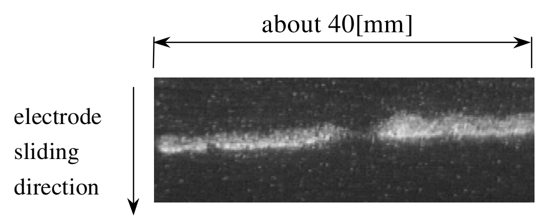


Figure 5. Light emission of the separating discharge

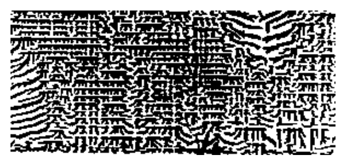


Figure 6. Discharge pattern when the sheet is negatively charged.

Model of Generating Image Degradation

Generating model of the image degradation is proposed considering the experimental results. Figure 7 shows the time sequence of the model near the discharge point between the PET sheet and the belt. Firstly, separating discharge occurs when the voltage across the gap between the sheet and belt is greater than the threshold voltage obtained from Pashen's law. Discharge gap is so large that strong discharge may happen and large amount of charge may move due to abnormal discharge (Fig. 7(a)). The potential of the PET sheet, where the charge is deposited, is so high that the surface discharge takes place (Fig. 7(b)). Toners deposited on the surface of the sheet move according to the potential distribution around the discharge point and the image degradation happens.(Fig.7 (c)) Since the potential of the PET sheet is dropped, following discharge can not take place for a while. As the sheet moves more, and the charged part is far enough from the discharge point, the potential of the sheet increases and the next discharge occurs again (Fig.7 (d)). This one cycle of the discharge and toner movement is rolled out and is repeated forming the periodic patterns.

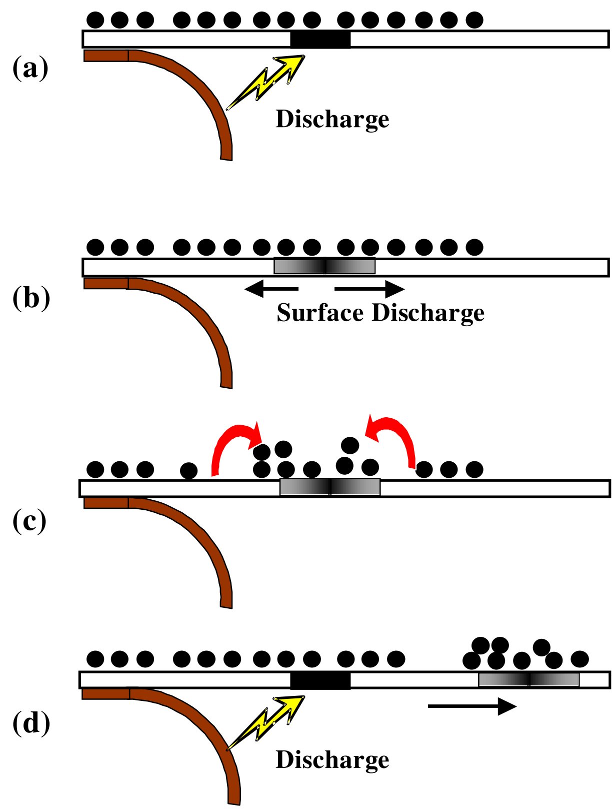


Figure 7. Generating model of image degradation

Simulation Model

In order to certify this new model, 2-dimensional simulation of the separating discharge with toner movement is carried out according to the following steps.

Step1: Calculation of the electric field to obtain the potential distribution around the PET sheet and the belt at time T. The belt is considered to be conductor in this simulation because its resistance is not so important parameter as is known from the experiment. Boundary Fitting Coordinate Mesh is used to fit the belt shape. Poisson's equation is solved by the finite difference method with consideration of the movement of the PET sheet.

Step2: Calculation of the abnormal discharge between the sheet and the belt. Using Paschen's law for the breakdown voltage, discharge gap can be derived. When the discharge occurs at the gap g[m], the amount of charge (dQ) deposited on the sheet is estimated from the empirical equation.

$$dQ[C/m^2] = -0.002\times\ln(g) - 0.0226 \quad (1)$$

Step3: Calculation of the surface discharge. The electric field after the abnormal discharge is recalculated because it disturbs the electric field. Next, the electric field strength E is estimated at every point on the sheet. If the electric field strength is higher than the breakdown field strength of the surface discharge(Elim), surface discharge may happen and charge(dq) is forced to move in the direction according to the electric field around the point.

$$dq = \mathbf{a}E \quad (\text{in case of } E > Elim) \quad (2)$$

where **a** is the parameters for the surface discharge. $Elim=3\times10^6$[V/m] and $\mathbf{a}=3\times10^{-14}$ are used in this study. Step3 should be repeated until surface discharge does not occur at any point on the PET sheet. After Step3, the electric field at time T is obtained.

Step4: Calculation of the toner movement. Force and movement of toner are calculated using discrete element method [7].

$F(T)=ma = Fe + Fq + Fa + Fr$

Fe: force due to electric field (qE)
Fq: force due to other charged toners
Fa: force due to adhesion force while toner is on the sheet
Fr : force due to air resistance while flying

$v(T+dt) = v(T) + (F(T)/m)\,dt$

$x(T+dt) = x(T) + v(T)\,dt + 0.5\,(F(t)/m)\,dt^2$

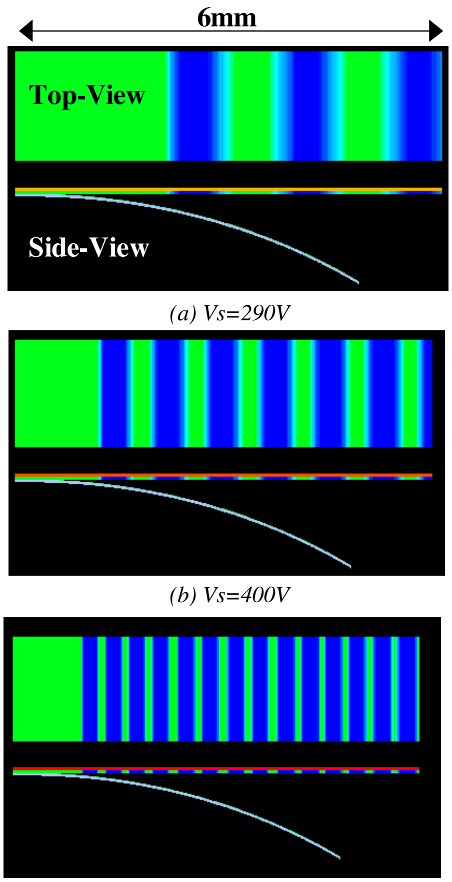
m : weight of toner q : charge of toner
v : velocity of toner x: position of toner
F : force on toner
dt : time step of the calculation

Step5: Time is advanced (T=T+dt). The PET sheet moves forwards, and then back to Step1.

Simulation Results

Surface Discharge Pattern

In order to confirm the separating discharge model, numerical simulation without toner movement is carried out and is compared with the experiment. The result is shown in Fig. 8, indicating the charge distribution on the backside of the PET sheet in gray scale. "Top-view" shows the charge distribution on the backside of the sheet. The gray parts indicate highly charged places. Figure 8(a) is the case of Vs = 290V, (b) is Vs = 400V and (c) is Vs = 560V. Periodic charging patterns can be recognized on the PET sheet. Figure 9 is the simulation result showing a series of charge distribution on the PET sheet for various surface potentials corresponding to Fig. 8. As the surface potential before separation increases, width and period of the discharge pattern become small. Figure 10 shows the experimental results of the discharge pattern obtained by cascade development. The potential distribution along the electrode sliding direction measured at every 32 µm using the high-resolution surface potential meter[8] is shown in Fig.11. The agreement of the numerical simulation with the experiment for the separating discharge phenomena is excellent.

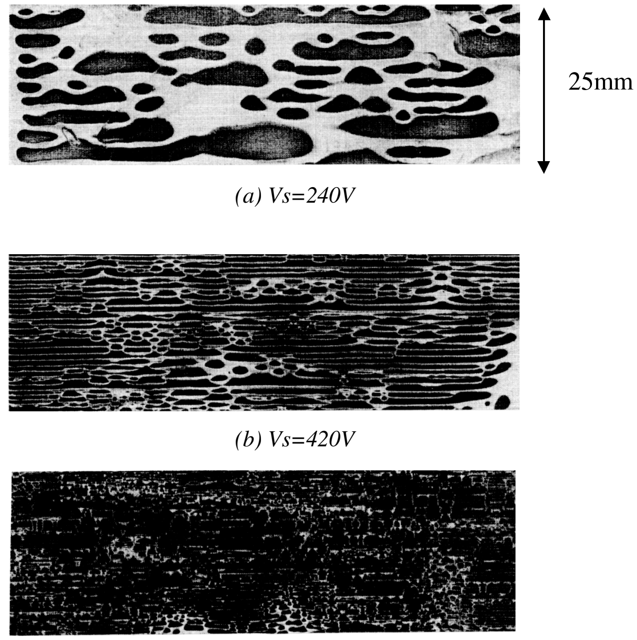


(a) Vs=290V

(b) Vs=400V

(c) Vs=560V

Figure 8. The separating discharge patterns for various surface potential obtained by simulation



(a) Vs=240V

(b) Vs=420V

(c) Vs=650V

Figure 10. The separating discharge patterns for various surface potentials obtained by experiment

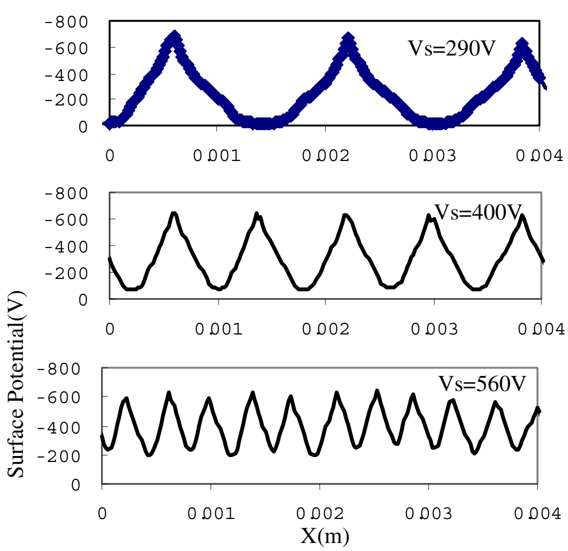


Figure 9. The Potential distribution on the PET sheet obtained by simulation

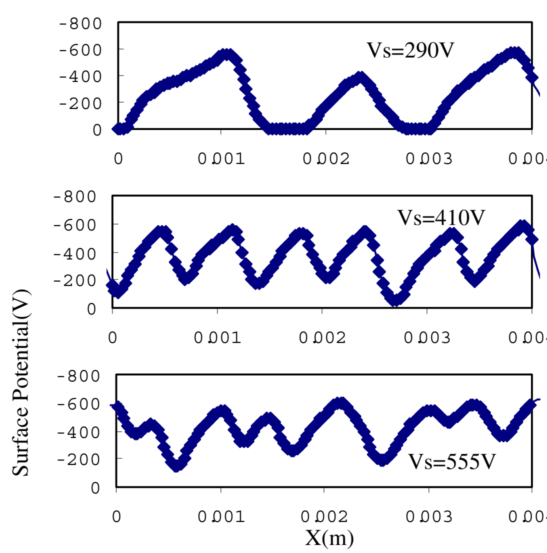


Figure 11. The Potential distribution on the PET sheet obtained by experiment

Image Degradation

The simulation result with the toner movement due to the discharge is shown in Fig. 12. Calculation parameters are shown in Table 1. In Fig.12, toner is shown in white color and its diameter is magnified 5 times for easy recognition. Lines of electric force are also shown as white lines. In the initial condition, toners are deposited uniformly on the PET sheet. When the surface potential before separation is 400V, toners are forced to move towards the discharge point due to the electric field made by discharge and image degradation occurs (Fig. 12 (a)). On the other hand, image degradation does not occur even though the separating discharge really happens when the surface potential is 560V (Fig. 12(b)). Figure 13 shows the relation between the maximum value of the electric field strength on the sheet after the separation and surface potential before separation. As the surface potential increases, the electric field strength decreases. In case of the highly charged sheet, as the separating discharge tends to occur easily, the discharge becomes weak according to Eq. (1). Thus, the electric field strength on the sheet is not strong enough to allow toner to move. In order to suppress the image degradation due to separating discharge, two proposals are considered. One is to suppress the separating discharge. The other is to make sheet highly charged before separation so as to make the discharge weak and to restrain toner movements.

(a) Vs=400V

(b) Vs=560V

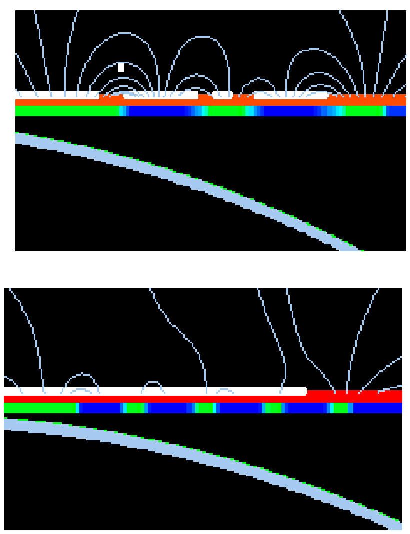


Figure 12. The simulation results of toner movement due to separation discharge

Table 1. Calculation parameters

Adhesion force between toner and sheet	7 nN
Toner diameter	7 μm
Toner q/m	20 mC/g
Sheet thickness	100 mm
Sheet dielectric constant	3
Sheet velocity	2.5 mm/s

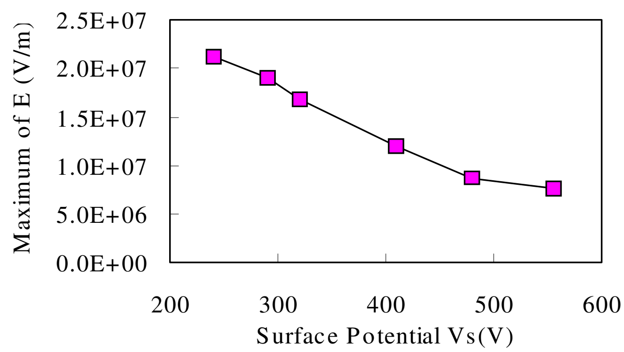


Figure 13. The relation between the electric field strength and surface potential Vs

Conclusion

It is confirmed from the model experiment that the image degradation in the belt transfer system is due to the separating discharge between the paper and the belt. Separating discharge pattern is simulated and it shows good agreement with the experimental one. Toner-movement due to discharge is also simulated using discrete element method and the result shows that image degradation occurs at low sheet potential Vs whereas it does not occur at high Vs.

Acknowledgment

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Biography

Masami Kadonaga received his B.S. and M.S. degrees in applied physics from University of Tokyo in 1987 and 1989, respectively. He joined Ricoh in 1989 as a member of research scientist, and has been working in the area of computational dynamics. Firstly, he studied the inkjet printing technology, and recently he has been working on the field of electrophotography.