Numerical Simulation of Toner Movement in a Transfer Process

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Abstract

A three-dimensional calculation of toner movement in a transfer region is carried out and toner scattering is simulated. This simulation includes an electric field calculation between two parallel plates and a calculation of toner movement. In order to estimate a force on a toner particle precisely, an electric field created by electrodes and surface charges, repulsive force of toner particles, mirror images of toner charges, a discharge phenomenon and toner adhesions are considered. A toner particle separates from the upper plate and begins to move downward when a transfer force overcomes the sum of the mirror force and the adhesion force. Movement of a toner particle is calculated according to Newton's motion law. From the simulation result, toner detachment happens before a discharge in a non-image region occurs. Because of the repulsive force and jumping the air gap, toner scattering happens and satellites are formed on the lower plate. In order to investigate toner scattering, a model experiment is carried out and is compared with the simulation. The number of satellites is compared between simulation and experiment, and the comparison shows good coincidence. This comparison confirms that this simulation model is useful for calculating toner movement in a transfer process. The model experiment and simulation indicates that toner scattering happens before discharges and the cause of toner scattering is mainly Coulomb's force.

Image Degradation in Transfer Process

Image degradation in a transfer process is a serious problem to obtain a fine image. Toner scattering, "halo" effect and "hollow character" degrade an image. The image degradation is not readily examined using a real copy machine because it is difficult to precisely determine under what specific conditions transfer occurs. It is useful to investigate transfer phenomena using a model experimental setup and a numerical simulation under well-defined conditions[1,2]. In our previous study with a model experiment, a relation between discharges and both a transfer efficiency and a retransfer was reported[1]. In this study, investigation of toner scattering with the model experimental setup and the numerical simulation is reported.

Objective

The objective is to investigate a toner scattering in a transfer process with the model experiment and a numerical simulation.

Experiment

The schematic diagram of the model experimental setup used in this investigation is shown in Fig. 1. The apparatus consists of a glass plate with electrodes and a piece of a transfer belt set on a lower electrode. The electrodes on the glass plate (Fig. 2) are made of ITO (Indium Tin Oxide) covered with a polycarbonate layer. At first, toners are deposited on the surface of the glass plate by a developer. Next, the glass plate moves above the belt. A transfer voltage is applied on the lower electrode and the transfer gap between the glass plate and the belt decreases. Because of an electric field created between the glass plate and the belt, toners move to the belt and transferred image is generated on the belt.

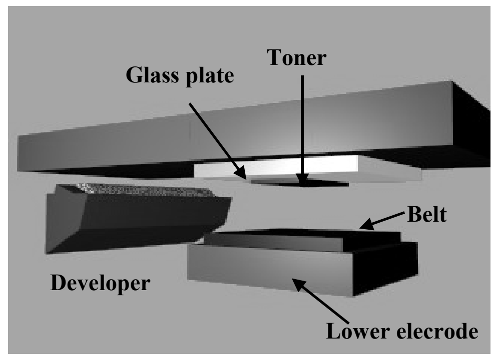


Figure 1. The schematic diagram of the belt transfer system

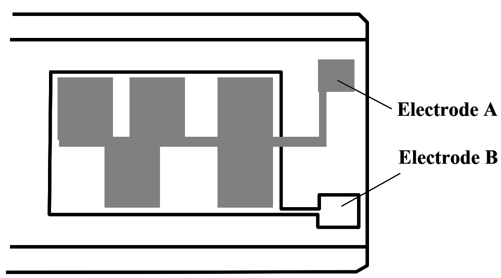
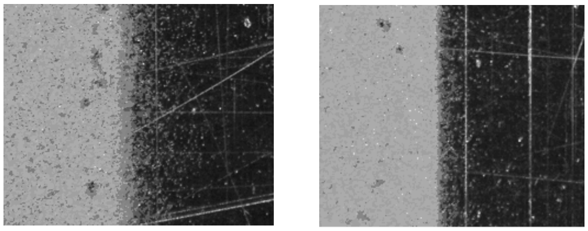


Figure 2. Top-view of the glass plate with the electrodes

The applied voltage on the electrode B, which is defined as V2, is changed and the transferred image on the belt is observed. Experimental condition is shown in Table 1. Figure 3 shows the toner images of V_2=0V and V_2=-300V. The area of toner scattering is measured and Fig. 4 results. As the absolute value of the applied voltage on the electrode B decreases, toner scattering becomes worse and the image on the belt is degraded. Figure 4 also shows that an increase of toner amount increases toner scattering.

Table 1: Experimental Condition

Potential on electrode A (V_1)	-100V
Potential on electrode B (V_2)	0 ~ -600V
Amount of toner after development	1.5, 0.7mg/cm^2
Charge-to-mass ratio of toner	-21μC/g
Transfer potential (the lower electrode)	400V
Transfer gap 300μm	~contact



(a) V_2=0V (b) V_2=-300V

Figure 3. Transferred image on the belt

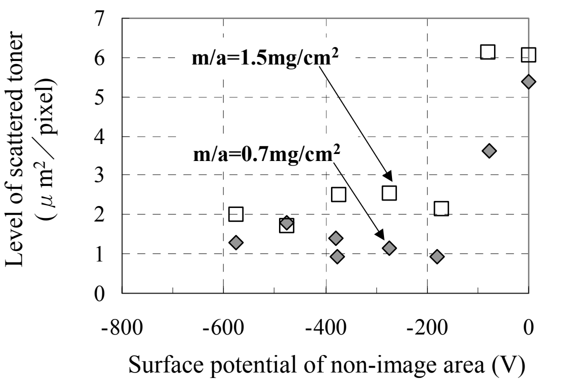


Figure 4. Relation between toner scattering and surface potential of non-image area [1]

Simulation Model

The formation of toner satellites probably is due to Coulomb's force between toners and the electric field around the toner. The force on a toner particle depends on its toner charge and the electric field created by other toners and the electrodes. In order to simulate toner movement precisely, the electric field around a toner particle before transfer should be calculated precisely. First step of this simulation is an exact calculation of an electric field explained as follows. The simulation area is shown in Fig. 5. Because of the principle of superposition, the electric field at the position (x,y,z) is the sum of the electric field created by the electrodes, that created by toner charges and that created by mirror charges. Let E_0, E_t and E_m be the electric field of electrodes, toner charges and mirror charges, respectively. The position of the n-th toner is (x_t, y_t, z_t). The vector from the position of n-th toner to the point (x, y, z) is denoted as (x_n, y_n, z_n) and is given by eq. (1).

$$(x_n, y_n, z_n) = (x - x_t, y - y_t, z - z_t) \tag{1}$$

The electric field without toners (E_0) is given by Poisson's equation. The electric field created by toners (E_t) is calculated from eq. (2).

$$E_t(x, y, z) = \frac{1}{4\pi\varepsilon_0} \sum_{i=1}^{n} \frac{q_n}{x_n^2 + y_n^2 + z_n^2} \tag{2}$$

Because mirror charges with dielectric layers are difficult to be considered precisely, each dielectric layer is assumed to be an air layer with the same dielectric thickness (thickness/ effective dielectric constant). The dielectric length between the upper electrode and the toner is given by eq. (3) and the dielectric length between the toner and the lower electrode is given by eq. (4), as is shown in Fig. 6.

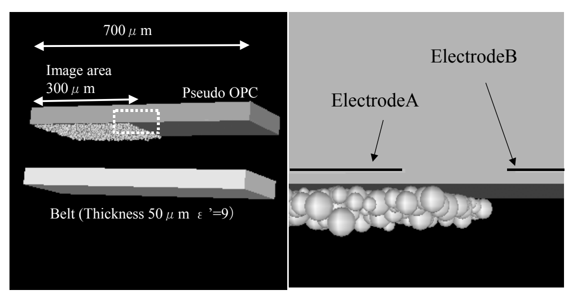
$$b = Z_1 + T_g / \varepsilon_g \tag{3}$$

$$a = Z_2 + T_b / \varepsilon_b \tag{4}$$

T_g: Thickness of the glass plate
T_b: Thickness of the belt
ε'_g: Effective dielectric constant of glass
ε'_b: Effective dielectric constant of belt
Z_1: Length between the upper plate and the toner
Z_2: Length between the lower plate and the toner

With this assumption, the electric field created by mirror charges can be estimated with eq. (5). The electric field around a toner can be obtained by the sum of E_0, E_t and E_m. This calculation method gives a precise electric field.

$$E_m(x, y, z) = \frac{1}{4\pi\varepsilon_0} \sum_{i=1}^{n} \sum_{j=-\infty}^{\infty} \left\{ \frac{1}{x_n^2 + y_n^2 + \{z_n - 2n(a+b)\}^2} - \frac{1}{x_n^2 + y_n^2 + \{z_n - 2n(a+b) - 2b\}^2} \right\} \tag{5}$$



(a) Schematic diagram of simulation area *(b) Magnified view of toners on the glass plate*

Figure 5. Calculation model

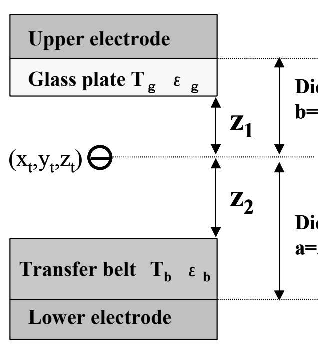


Figure 6. Schematic of dielectric length a and b

Discharge between the glass plate and the transfer belt is considered. When the potential difference between the glass plate and the belt is greater than the threshold value, which is well known as Paschen's voltage, ionization of air molecules occurs. Then, positive and negative charges are deposited on the glass plate and the belt respectively to reduce the electric field in the transfer gap. As adhesion properties of toner particles are known to affect transfer, the adhesion force distribution of toners is assumed as is shown in Fig. 7. When the transfer force on a toner particle is greater than its adhesion force, the toner particle separates from the glass plate and moves downward. Toner movement is calculated with Newton's motion law.

$$F(t) = m \cdot a = q \cdot (E_0 + E_t + E_m) \tag{6}$$

$$v(t + dt) = v(t) + (F(t) / m) \cdot dt \tag{7}$$

$$x(t + dt) = x(t) + v(t) \cdot dt + 0.5 \cdot (F(t) / m) \cdot dt^2 \tag{8}$$

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

It is assumed that a repulsive force between two toners, which contact each other, is greater than the theoretical value given by eq. (2) because of non-uniform charge distribution on the toners. In this simulation, a repulsive force between toners in contact is multiplied by 1.0~5.0, which is obtained by a random number. The transfer gap decreases in the speed of 300mm/s and the grid of calculation is re-meshed. Then go back to the first step and do the same steps repeatedly till the gap becomes 14μm

Simulation Results

Calculation is carried out with the condition shown in Table 2. The sequence of toner movement with V_2=0V and V_2=-300V are shown in Fig. 8. A toner particle on the glass plate, a moving particle and a particle deposited on the belt are shown as a solid circle in white, in black and in gray, respectively. A discharge region is also indicated with lines (in the figure of V_2=-300V at gap 14μm). These results indicate that the toner scattering happens before a discharge happens and Coulomb's force plays a significant role in toner scattering. The simulation result of the toner image on the belt after the transfer is shown in Fig. 9. The number of scattered toners is counted and shown in Fig. 10. As the potential of the non-image area (V_2) decreases, toner scattering is suppressed. This tendency is consistent with the experiment shown in Fig. 4. This comparison shows that this simulation model is verified and toner scattering happens due to Coulomb's force when toner particles jump in an inlet of the transfer nip.

Table 2: Simulation Condition

Potential of image area V_1	-100V
Potential of non-image area V_2	0 ~ -800V
Amount of toner after development	1.02 mg/cm^2
Charge per mass ratio of toner	-21μC/g
Transfer potential	400V
Transfer gap	275 ~14μm

Conclusion

Numerical simulation of toner movement based on the mirror charge method is carried out and comparison between the simulation and the experiment shows good agreement. The model experiment and simulation indicate that toner scattering happens before discharge and the cause of toner scattering is mainly Coulomb's force.

References

1. T. Takahashi, S. Iwai and M. Kadonaga, Proceedings of IS&T NIP19, pp.28-31(2003).
2. N. Nakayama and H. Mukai, Proceedings of Pan-Pacific Imaging Conference/Japan Hardcopy '98, pp261-264 (1998).

Author 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. He received his Doctor of Engineering from Tokyo University of Agriculture and Technology in 2003.