The study of the difference of toner-motion among several development systems

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Abstract

The development system in electrophotography had been numerically investigated using a three-dimensional dynamic model. The simulation of the toner dynamics in the development process was carried out using the Finite Difference Method (FDM) for the electric field calculation, the superposition method for the magnetic field and the Distinct Element Method (DEM) for the calculation of particle motion in the development area. A non-magnetic development system, a magnetic single-component development system and two-component development system were analyzed with these methods. The parameters of the development process for numerical simulation were possibly the same values for the development systems. The followings were deduced from this study. (1) The difference of particle charge distributions made the characteristic among individual development systems. (2) A non-magnetic development system was most influenced by the space charge limit. (3) The toner chain of the magnetic single-component development system made a contribution to increasing the number of effective toner for development. (4) Toner motion in the two-component development system was controlled by the charge-balance of toner and carrier particles.

INTRODUCTION

Electrophotography is the technology that control the motion of toner particles. The control system has many devices for carrying the toner particles to the particular point. The dominant force of moving toner is electric force. The development system is the visualization process of the latent image using the toner particles applying the electromagnetic force.

There are many types of study of the numerical analysis to clarify the particle motion with the growth of computing capacity has been reported at the present day. However, only a few studies have been reported for the quantity analyses of the development process or analysis of the characteristic of the development system.

Our past study[4,5] showed that the quantitative analysis of development process could be made by considering the three interactions, which were electrostatic interaction, magnetic interaction and mechanical interaction. We made it possible to apply to a two component development system to use the three-dimension model and the mixed of non-magnetic and magnetic particles. A non-magnetic development system, a magnetic single-component development system and two-component development system were analyzed with these methods.

ANALYSIS MODEL

A three-dimensional modeling was conducted to clarify toner dynamics in the development process. A motion equation (1) was calculated for each particle i, of which mass is m, at each time steps, where mechanical interaction force, electrostatic force, and magnetic force were included in the force applied to the particle.

$$m_i \frac{d^2 \boldsymbol{x}_i}{dt^2} = \boldsymbol{F}_{i_{mech}} + \boldsymbol{F}_{i_{elec}} + \boldsymbol{F}_{i_{mag}} \qquad \boldsymbol{x} = (x, y, z) \;, \tag{1}$$

The contact force F*mech* caused by mechanical interactions and toner motion in the field was calculated by the Distinct Element Method (DEM).[1] The electrostatic force to the charge particle was given by Eq. (2), where the electrostatic field E was calculated to solve the Poisson's equation (3) by the Finite Difference Method (FDM). Here, ρ is the charge density, ε_0 is the permittivity of free space, and ε_r is the relative dielectric constant.

$$\boldsymbol{F}_{elec} = q\boldsymbol{E}\,, \tag{2}$$

$$-\nabla \cdot (\varepsilon_0 \varepsilon_r \boldsymbol{E}) = \rho, \tag{3}$$

The magnetic force F*mag* to the magnetic moment p was given by following expression under the assumption that each toner behaves as a magnetic dipole placed at the center of the toner particle.[3]

$$\boldsymbol{F}_{\boldsymbol{mag}} = (\boldsymbol{p} \cdot \nabla)\boldsymbol{B}\,, \tag{4}$$

$$\boldsymbol{p}_i = \frac{\pi a_i^3}{2\mu} \frac{\mu - 1}{\mu + 2} \left[\boldsymbol{B}_i^{'} + \sum_{j=1(j \neq i)}^{N} \frac{\mu_0}{4\pi} \left(\frac{3\boldsymbol{p}_j \cdot \boldsymbol{r}_{ij}}{|\boldsymbol{r}_{ij}|^5} \boldsymbol{r}_{ij} - \frac{\boldsymbol{p}_j}{|\boldsymbol{r}_{ij}|^3} \right) \right] , \tag{5}$$

where μ_0, μ, a p_j, B_i', and r_{ij} are the permeability of free space, relative permeability, particle diameter, magnetic dipole moment, applied magnetic field at the j-*th* particle, and position vector from the j-*th* to the i-*th* particle, respectively. The development system in electrophotography has been numerically investigated using a three-dimensional dynamic model. Simulation of toner dynamics in the development process was carried out using the Finite Difference Method (FDM) for the electric field calculation, the superposition method for the magnetic field and the Distinct Element Method (DEM) for the calculation of particle motion in the development area.

Electric Field Calculation

The features of the electric field analysis model were as follows.

(1) The analytic region was the two layers model that included a dielectric layer as the photoreceptor.
(2) By varying the voltage boundary condition with time, we simulated the AC development bias.

(3) The electrostatic field was calculated to solve the Poisson's equation by the Finite Difference Method on the spatially-discretized orthogonal grid.
(4) The toner and carrier charge were assigned to the grid points in the particle region.
(5) Similarly, the dielectric constant of the area was varied as the ratio of the particle occupation.

The followings were the conditions for the electric field calculation.

(1) The development analysis was calculated in the area with 168μm in width, 168μm in depth and 268μm in height.
(2) The image surface along X-Z plane is 168μm x 168μm cross section that mean 4 x 4 pixel in 600dpi image pattern.
(3) The analysis area was divided into 409,825 grids for the electric filed analysis by F.D.M.
(4) The calculation time was 1.286e-3 sec.
(5) A time spacing for particle motion analysis was 1e-9 sec. and the electric filed was recalculated every 1e-6 sec.
(6) The initial particle position was decided randomly in the development area.

Making the Latent Image

The distribution of the exposure intensity was calculated from the profile of the optical spot of the exposure light and the exposure pattern data by using convolution integral method. The static spot profile of semiconductor laser beam was applied as exposure light. The surface charge density distribution on the surface of the photoreceptor was given from exposure intensity distribution by transformation of photo-induced discharge curve (PIDC).

The high-speed calculation of electric field

It was necessary to repeatedly calculate the electric field with the particle charge to analysis the particle motion in the development process. Therefore, we needed the computationally effective method to solve the Poisson equation. Thus we used three-dimensional Multigrid method[2], which was proposed to highly-effective iterative solution technique. The Multigrid method could calculate it 200x faster than the standard SOR method, and 8.5x faster than the direct method with LAPAC in 65,536 grids model.

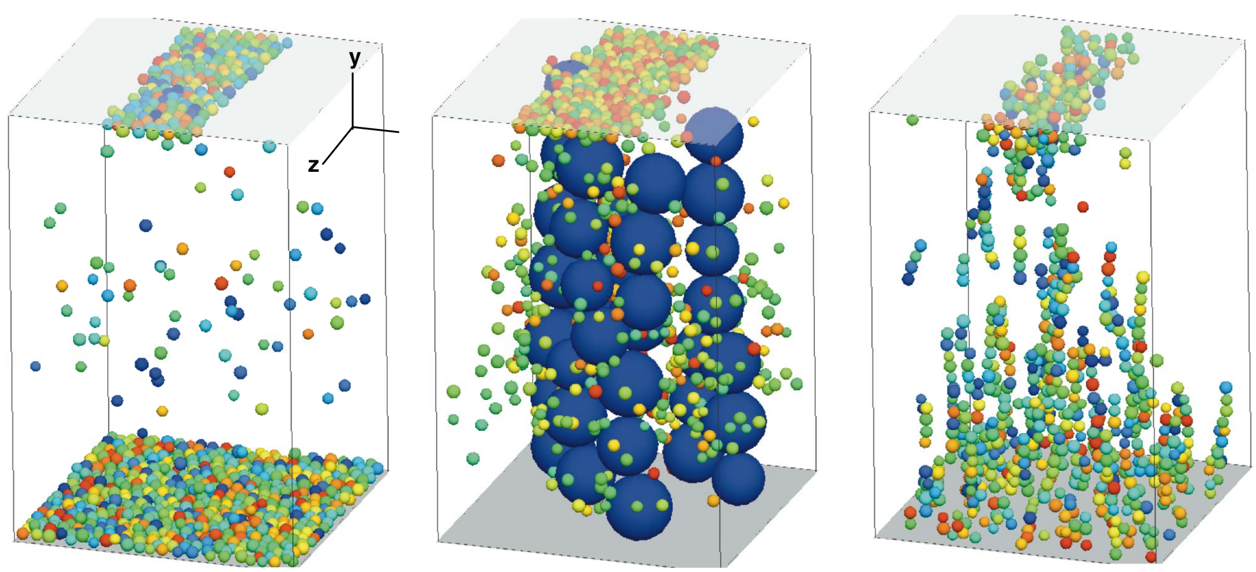
RESULTS & DISCUSSION

At first, the influence of toner motion was calculated among the models of the three different development systems, that was a non-magnetic development system, a magnetic single-component development system and a two-component development system. The parameters of the development system were set up the same values among the several development systems to a maximum extent. The specifications of the particle were listed in Table 1. The values of the carrier particle charge were determined to equalize the whole carrier charge (-) and the whole toner charge (+). The two lines image was set resolution to 600dpi as the latent image.

Table 1: Particle Specifications

	Toner	Carrier	Mag. Toner
Diameter (*μm*)	6 - 8	15 - 20	6 - 8
Charge (*μC/g*)	10 - 30	-1.2 - -0.8	0 - 15
SG	1.2	3.5	1.6
ε	2.0	5.0	2.0
μ	-	5.0	1.8

Figure 1(a)-(c) showed the snapshot of the simulated various development systems at 1.07e-3 sec. in model time. The situation of this scene had been just applied to promotion bias. The



(a) non-magnetic development system *(b) two-component development system* *(c) Magnetic Single-component development system*

***Figure 1**. The difference of simulated development process among various development systems.*

development roll is bottom side, and the photoreceptor is upper side. The remarkable point of this results was a number of effective particles in the development gap. In a non-magnetic development system, there were few toner particles in the development gap, because many toner particles still remained on the development roll. On the other hand, in a magnetic single-component development system, some particles in chains were left on the development roll. In the two-component development system, most of particles were flying in the gap.

Figure 2(a)-(c) showed the simulated toner image that was extracted from the calculated results. The clipping area was 100 mm height of midsection from y-axis. N of Figure 2 was the number of toner particles in this area. Therefore, a non-magnetic development system had the least number of toner particles that was effective for development. The number of toner particles in the non-magnetic development system was 1/3 of that in the magnetic single-component development system, and 1/6 of that in the two-component development system.

The reason of small amount of effective toner particle in a non-magnetic development system was space charge limit. Because the toner particles, which had homopolarity charge, generate the repelling force among these particles, the number of toner particles was restricted in the development gap. In other words, it indicated that electrostatic repulsion decided the amount of toner particles in this development system. The density of the toner particles in the cross section view in a magnetic single-component development system was the same as that in a non-magnetic development system. However, the perpendicular density of toner particles increased due to the toner chain made from the magnetic interaction force between the magnetic toner particles. In this zone, the number of particles in the two-component development system was more than that of a non-magnetic development system. In the two-component development system, the toner particles crowded round the carrier particles that was indicated by gray color in Fig. 2(b). Because of the space charge neutralization, the charge of the toner particles could be ignored when the toner particles were around carrier particles. Accordingly, almost every toner particles were moving along the chain of carrier particles.

The followings were deduced from the simulated results.

(1) There really was the difference of the toner particle motion among these development systems.
(2) The difference of particle charge arrangement caused the distinctive toner motion.
(3) These simulated results provided us a hint of the characteristic of development system.

Secondly, the influence of the carrier charge on toner motion in a two-component development system was investigated. The electrical resistance and the charge property were major parameters of the characteristics in a two-component development system. In this study, we simulated the electrical property about the particle charge varieties between the toner particle and the carrier particle.

Analytic conditions of each model were as follows.

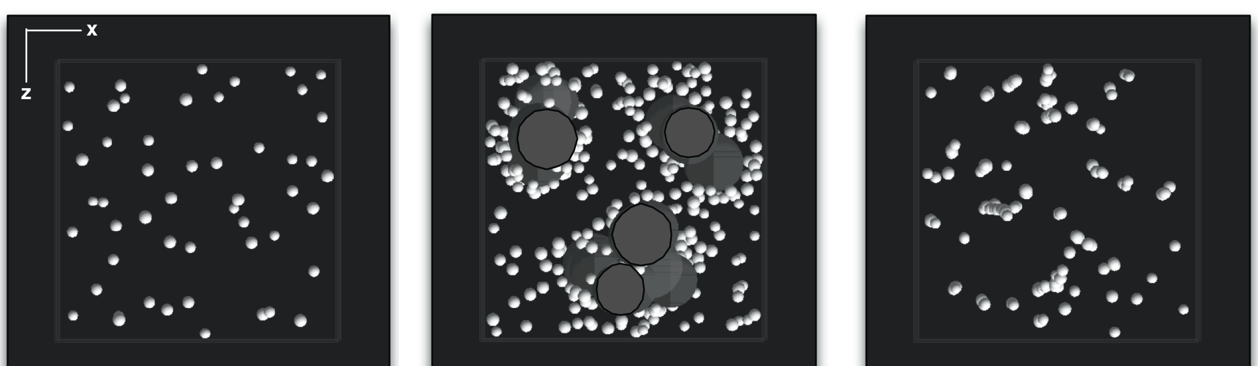
Model A: equivalent charge model.
Number of particle Toner(T):768, Carrier(C):36
Average charge T:~20μC/g, C:~1.0μC/g
Whole charge T:~3.0e-12C, C:~3.0e-12C
Simulated results had been calculated as before (Fig. 1(b)).

Model B: richer carrier charge model
Number of particle Toner(T):768, Carrier(C):36
Average charge T:~20μC/g, C:~2.0μC/g
Whole charge T:~3.0e-12C, C:~6.0e-12C

Model C: Charge-balanced model
Number of particle Toner(T):1536, Carrier(C):36
Average charge T:~20μC/g, C:~2.0μC/g
Whole charge T:~6.0e-12C, C:~6.0e-12C

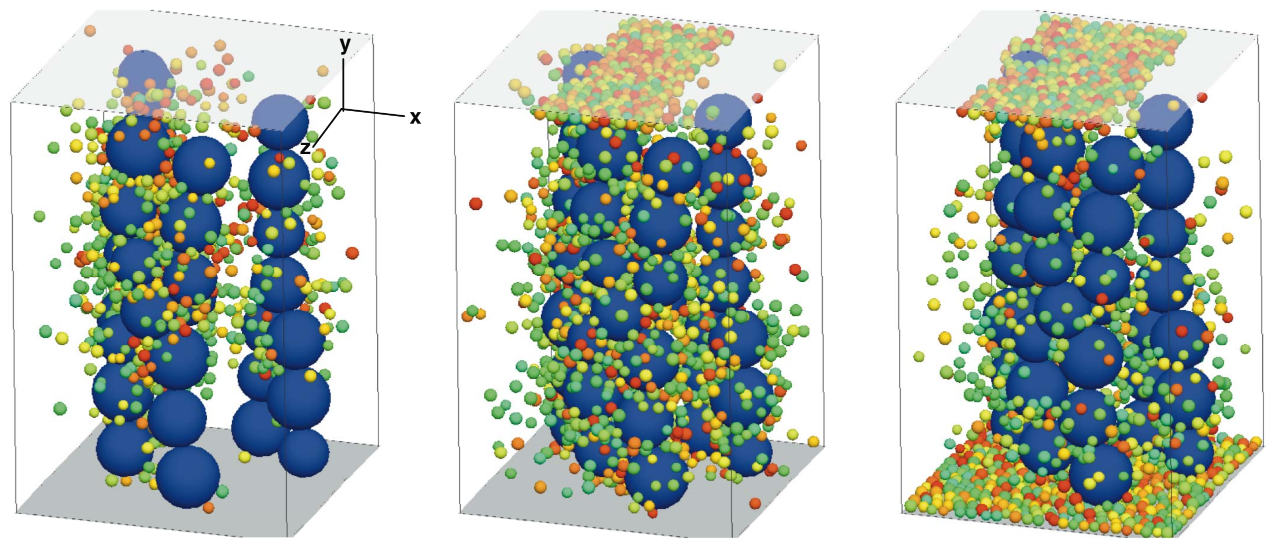
Model D: richer toner charge model
Number of particle Toner(T):1536, Carrier(C):36
Average charge T:~20μC/g, C:~1.0μC/g
Whole charge T:~6.0e-12C, C:~3.0e-12C

Figure 3(a)-(c) showed the results of the simulated toner motion in the two-component development system. It was found that Model B ("carrier charge rich" model) was impossible to develop. The toner particles once tried to move to develop the latent image when forward bias applied, however, all of toner particle was pulled back from the photoreceptor by changing the bias to back-ward side. This calculated results represented the



(a) non-magnetic development system (N=51) *(b) two-component development system (N=290)* *(c) Magnetic Single-component development system (N=147)*

***Figure 2**. Simulated Toner Image through the clipping view, and number of toner particles in this area.*



(a) Model B *(b) Model C* *(c) Model D*

***Figure 3**. Comparison of simulated toner image by particle model in two-component development system.*

simulated scavenging effect. The results of particle motion on Model C had similar behavior to Model A, furthermore, the particle motion of Model D denoted the same tendency of non-magnetic development system.

The followings were deduced from the simulated results.

(1). This simulated model could reproduce some development phenomena in the two-component development system.
(2). The toner particle motion depended heavily on the ratio of the charge between toner and carrier.
(3). The amount of carrier charge was the primary factor of the two-component development system.

Conclusions

The development system in electrophotography had been numerically investigated using a three-dimensional dynamic model. The difference of particle charge distribution made the characteristic among individual development system. Toner motion in the two-component development system was controlled by the charge-balance between toner and carrier particles.

References

[1] P. A. Cundall and O. D. L. Strack, A Discrete Numerical Model for Granular Assemblies, Geotechnique, **29**-1, 47. (1979).
[2] William L. Briggs, Van Emden Henson, Steve F. McCormick, A Multigrid Tutorial (Society of Applied Mathematics, Philadelphia, PA, 2000)
[3] N. Nakayama, H. Kawamoto, S. Yamada and Sasakawa, Statics of Electromagnetic Bead Chains in Electromagnetic Field, Proc. IS&T's NIP18, pg. 742. (2002).
[4] M. Nakano and H. Kawamoto, Investigation of Non-Magnetic and Non-Contact AC Development Process in Electrophotography, Proc. JSME-IIP/ASME-ISPS Joint Conf. MIPE, pg. 331. (2002)
[5] M. Nakano, H. Kawamoto and I. Itoh, The Influence of Toner Charge on the Magnetic Chain in the Magnetic Single-Component Development System, Proc. IS&T's NIP19, pg. 74. (2003)

Author Biography

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