The Influence of Toner Charge on the Magnetic Chain in the Magnetic Single-Component Development System

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Abstract

A magnetic single-component development process in electrophotography has interesting characteristics on a magnetic and electrostatic interaction of toner particles. Magnetic force restrains toner adhesion to non-image area and this feature enhances the development. However, long chains made by magnetic interaction force between magnetic toner particles deteriorate toner-image quality on the photoreceptor. It is known from a past experimental study that the magnetic chain length is influenced not only by the magnetic field but also by the electrostatic charge of toner particles. This study confirmed it by using two-dimensional numerical analysis. Simulation of toner dynamics was carried out using the Finite Difference Method (FDM) for the electric field calculation and the Distinct Element Method (DEM) for the calculation of charged magnetic toner motion in the magnetic and electrostatic field. The following were deduced form the investigation. (1) The chain length of toner particles was shortened by the toner charge. (2) In the case that particles does not include wrong-sign toner, charge distribution does not change the chain formation but wrong-sign toner particles influence the chain length and number. (3) The magnetic chain was reconstructed under the application of AC biased potential at the development gap. (4) Toner particles with wrong-sign toner caused a defect of chain images.

Introduction

Although there are several types of the development system,[1] the magnetic single-component development system is used in most black-and-white (B/W) laser beam printers with wide speed range, because it can realize high print quality with a simple configuration. Magnetic attraction force prevents several development problems, for example, toner sticking to non-image area and toner scattering. However, the system has a potential to make an image defect due to chain formation. Magnetic chains of toner particles made by magnetic interaction degrade image quality on the photoreceptor. Figure 1 shows an example of a developed toner image of 6 pt Japanese KANJI font on a photoreceptor. Toner chains exist around the regular image.

Although there are a lot of studies on the magnetic chain for a dual-component system,[2,3] no investigation has been reported for the single-component system and on an interaction with the toner charge. Accordingly, influence of toner charge on the formation of the magnetic chain was investigated experimentally and theoretically to utilize for the improvement of the magnetic single-component system in electrophotography.

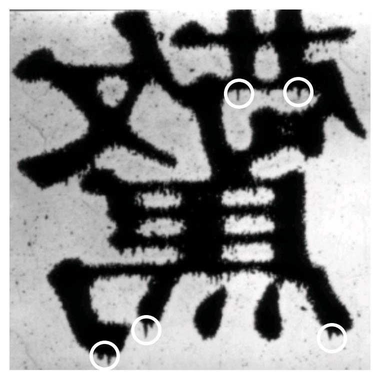


Figure 1. An example of developed toner image of 6 pt Japanese KANJI font on the photoreceptor. Defects in white circles were caused by magnetic chains.

Experimental

It is known from a past experimental study that the magnetic chain length is influenced not only by the magnetic field but also by the electrostatic charge of toner particles.[4] An existing commercial printer was modified to produce a toner layer of different charge distribution on a development roll. Figure 2 shows single-component development system that has a rotary doctor (RD).[4] A blade used for doctoring with a conventional developer was replaced to the rotary doctor. A development roll and a rotary doctor rotate in opposite direction at the gap, and have stationary magnet rolls in them. Toner particles were charged and formed chains after doctoring. Toner particles at the lower part in chains have relatively high charge, because toner particles were charged by the frictional contact with the development roll. When the rotary doctor rotates, it prevents to participate the low-charged toner particles by removing them from tips of chains. Therefore, this developer generates chains of highly charged toner particles for the development. Figure 3 shows the charge distribution of toner on the development roll, measured by E-SPART Analyzer. (Hosokawa Micron Corp.)

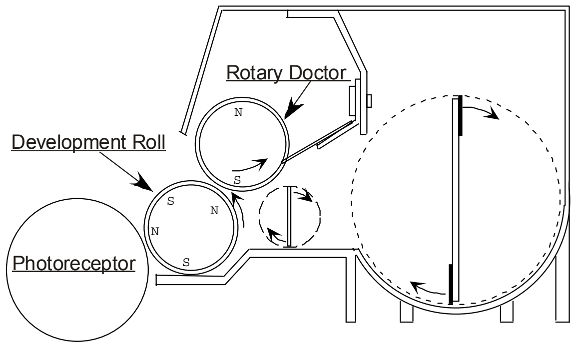


Figure 2. Rotary doctor developer for magnetic single-component development system.

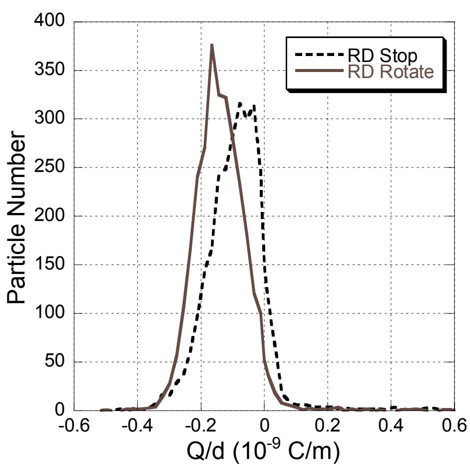


Figure 3. Charge distribution of toner particles on development roll with and without rotation of rotary doctor.

The toner image shown in Fig. 1 was developed in case that the rotary doctor was stopped. In the same way, Fig. 4 shows the toner image on the photoreceptor with the rotation of the rotary doctor. No chain exists around the regular image and the image have clear boundary between image and non-image area with high resolution. This evidence suggests that an interaction between the magnetic and electrostatic features determines the formation of the chain defect.

An averaged toner charge increased gradually with the RD speed as shown in Fig. 5. Furthermore, Fig. 6 shows the influence of toner charge on chain length and rate of wrong-sigh toner. The following were deduced form these experimental results. (1) The RD rotation changes toner parameters such as averaged charge density, charge distribution, and rate of wrong-sigh toner. (2) The RD rotation shortens the chain length on the development roll. This feature seams to improve the developed image quality. However, it has not been clarified which and how parameters shorten the chain length, because the charge distribution and averaged toner charge correlate to each other and it is impossible to change them independently by an experimental method. For this reason, the influence of those toner parameters were investigated by a simulated method.

Figure 4. Developed toner image on the photoreceptor with RD rotation.

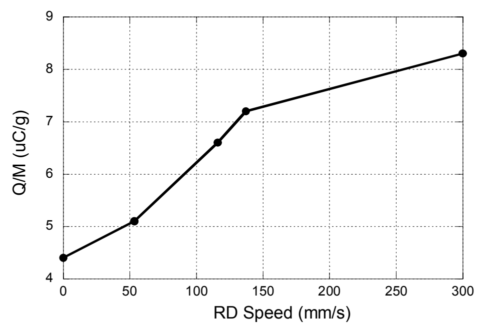


Figure 5. Variation of toner charge on the development roll.

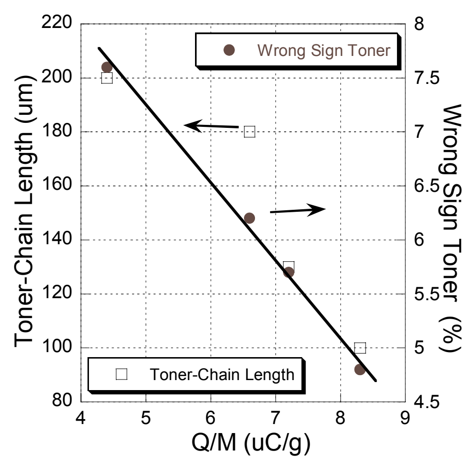


Figure 6. Influence of toner charge on chain length and rate of wrong-sigh toner.

Simulation

A two-dimensional modeling was conducted to clarify toner dynamics in the chain formation 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.

$$m_i \ddot{\boldsymbol{x}}_i = \boldsymbol{F}_{i\,mech} + \boldsymbol{F}_{i\,e} + \boldsymbol{F}_{i\,mag} \qquad \boldsymbol{x} = (x, y) \tag{1}$$

The contact force $\boldsymbol{F}_{mech}$ caused by mechanical interactions and toner motion in the field was calculated by the Distinct Element Method (DEM).[5] The electrostatic force to the charge particle was given by Eq. (2), where the electrostatic field $\boldsymbol{E}$ 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.

$$\boldsymbol{F}_e = q\boldsymbol{E} \tag{2}$$

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

The magnetic force $\boldsymbol{F}_{mag}$ to the magnetic moment $\boldsymbol{p}$ 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]

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

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

where μ_0, μ, a $\boldsymbol{p}_j$, $\boldsymbol{B}_i'$, and $\boldsymbol{r}_{ij}$ 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.

Chain Formation

A formation of chain was calculated in the area with 500 µm in width and 500 µm in height. Figure 7 shows the FDM mesh pattern and boundary conditions for the electrical field. A base surface is the development roll and the magnet roll exists under it. A coupled calculation was performed with respect to the electromagnetic field and toner motion.

Development of Line Image

After calculating the chain formation, development of a line image was calculated. A Numerical simulation model of the process was proposed in the previous report.[6] A lateral line image on the photoreceptor was added at the upper end of the calculation domain as shown in Fig. 8. Distribution of the electric charge density of an image surface on a photoreceptor $\sigma(x)$, the electrostatic latent image, was derived from a spot profile of a laser beam. The AC bias voltage was applied to the development roll as the time variation of the boundary condition on the development roll. The development gap was changed with time to simulate the progress of the process.

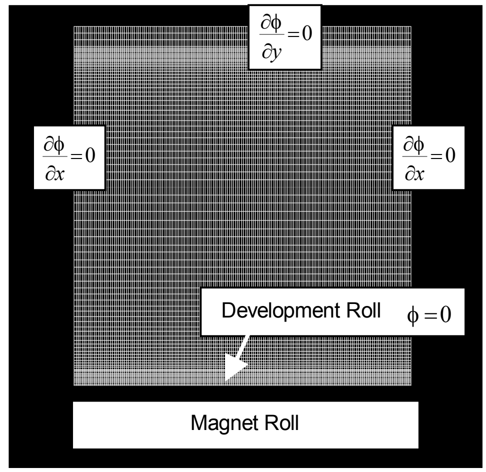


Figure 7. Model to calculate electrostatic field with FDM for simulation of chain formation. (ϕ: potential, $\boldsymbol{E}=-$grad ϕ)

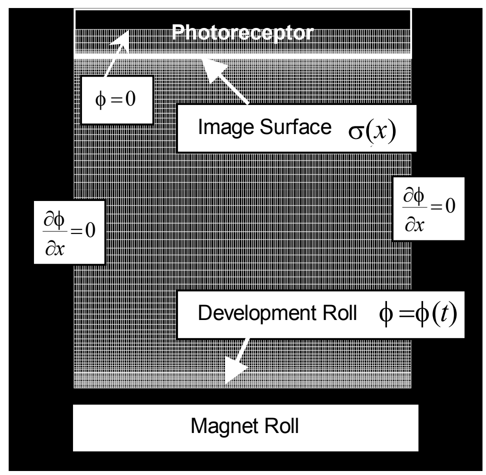


Figure 8. Model to calculate electrostatic field with latent image for simulation of development.

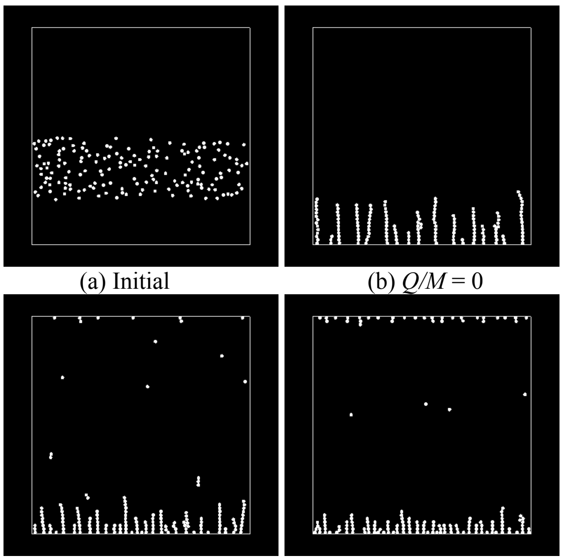
Results and Discussion

At first, the influence of toner charge on the generation of magnetic chains was calculated. Figure 9 (a) shows initial toner distribution that was arranged at random position in space. Number of calculated toner particles, 8 µm in diameter, is 160. Figure 9 (b)~(d) are simulated toner profiles at quasi-steady state (t = 2.0 ms). Although the chain length was under-estimated in the two-dimensional model,[7] the calculated results qualitatively showed the tendency that the chain length was short if the charge density of toner particles was large. This agreed with the experimental evidence shown in Fig. 6.

Because it has been reported that the chain profile is basically determined so as to minimize the potential energy,[3] the magnetic energy U_m and electrostatic energy U_e were estimated by the Eqs. (6) and (7).

$$U_m = \sum_{j=1}^{N} \boldsymbol{p}_j \cdot \boldsymbol{B}_j \tag{6}$$

$$U_e = \sum_{i=1,j=1,(i\neq j)}^{N} \frac{q_i q_j}{4\pi\varepsilon_0 r_{ij}}. \tag{7}$$



(a) Initial (b) $Q/M = 0$

(c) $Q/M = 5$ μC/g (d) $Q/M = 10$ μC/g

Figure 9. Initial and simulated chain profiles.

Time variation of magnetic and electrostatic potential energies was shown in Fig. 10. The magnetic energy decreases with the growth of magnetic chains at any condition of toner charge but converged magnetic energy is high for highly charged toner particles. On the other hand, electrostatic energy is increased as the growth of magnet chains. The following were deduced form the simulated results. (1) Both of the magnetic and electrostatic energies are high for highly charged toner particles. (2) Because the electrostatic energy compensates to decrease the magnetic energy, the chain length of toner particles might be shortened by the toner charge.

Secondly, it was investigated on the influence of the charge distribution of toner particles and the existence of wrong-sign toner on the chain length. The charge distribution was generated randomly but the averaged charge density was settled approximately 5 μC/g in all cases. Figure 11 shows the simulated results. The shape of calculated chains can be classified in two groups. Toner particles without wrong-sign toner, Figs. 11 (a) and (b), was similar configuration about the chain length and chain number. On the other hand, in the case that toner particles had wrong-sign, Figs. 11 (c) and (d), chains became longer as increasing the range of charge distribution. This feature is also qualitatively explained by the variation of potential energies. Figure 12 shows time variation of magnetic and electrostatic energies. The magnetic energy was not affected by the distribution of toner charge but the electrostatic energy was classified in two groups likewise the chain formation. Each group had similar energy value in spite that they had the different charge distribution. The electrostatic energy of wrong-sign toner particles was lower than that of the common-sign toner. One of possible reasons is that the electrostatic energy between a pair of opposite-sign particles gives negative.

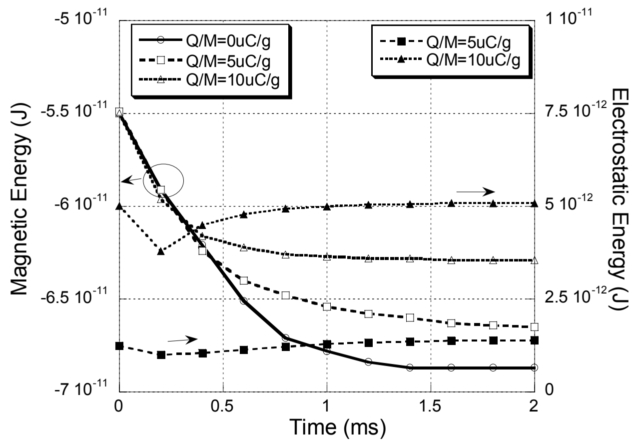
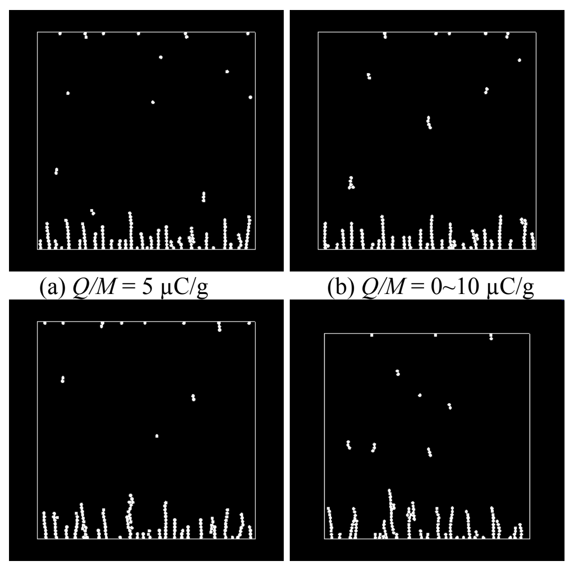


Figure 10. Time variation of magnetic and electrostatic potential energies during chain formation with various Q/Ms.



(a) $Q/M = 5$ μC/g (b) $Q/M = 0\sim10$ μC/g

(c) $Q/M = -5\sim15$ μC/g (d) $Q/M = -10\sim20$ μC/g

Figure 11. Simulated chain profiles with distributed charge densities.

Finally, development process on a latent line image was calculated with the calculating condition shown in Fig. 8. Figure 13 shows simulated toner motion with the application of AC bias voltage at the time when pull-back field was applied. The field shortened the chain length. Figure 14 shows snapshots of developed image of 600 dpi 3-line images when the development gap was smallest. Here, simulated profiles shown in Figs.11 (b) and (c) were used for the initial conditions. Chains without wrong-sign toner particles were shortened by the reconstructed effect; on the other hand, toner particles with wrong-sign toner caused the chain image. The calculated results showed good agreement with KANJI photograph given in the beginning of this paper.

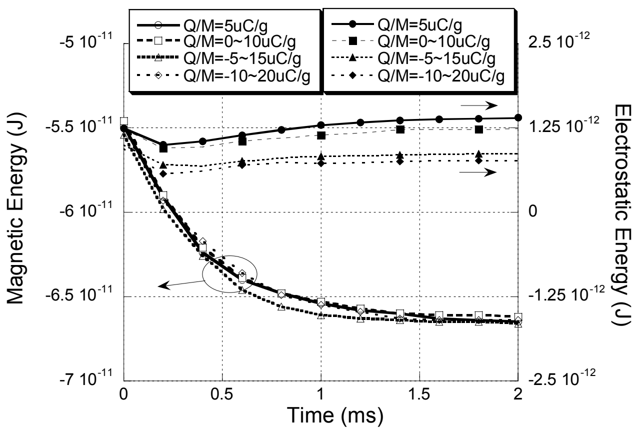
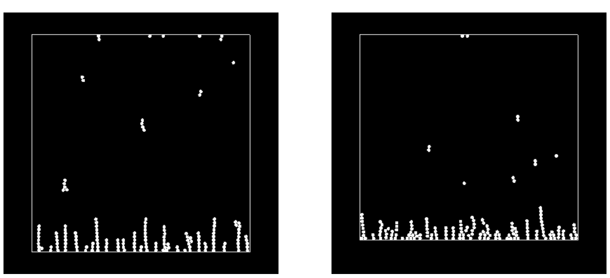
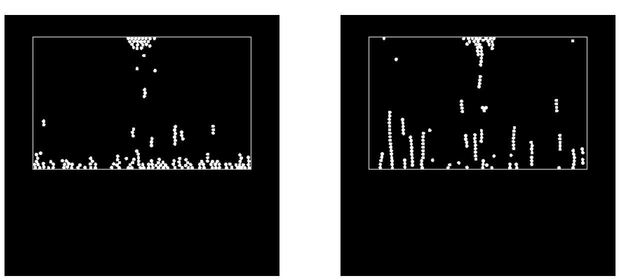


Figure 12. Time variation of magnetic and electrostatic potential energy during chain formation with various Q/Ms.



(a) initial (t = 0 ms) (b) in pull-back field (t = 0.278 ms)

Figure 13. Simulated reconstruction of chains with the application of AC bias voltage (Q/M = 0~10 μC/g).



(a) Q/M = 0~10 μC/g (b) Q/M = –5~15 μC/g

Figure 14. Simulated development process on latent image with the application of AC bias voltage.

Conclusions

The influence of toner charge on the formation of the magnetic chain was investigated. The following were deduced form the investigation.

(1) The chain length of toner particles was shortened by the toner charge.

(2) In the case that particles does not include wrong-sign toner, charge distribution does not change the chain formation but wrong-sign toner particles influence the chain length and number.

(3) The magnetic chain was reconstructed under the application of AC biased potential at the development gap.

(4) Toner particles with wrong-sign toner caused the chain image.

References

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Biography

Masao Nakano holds a BS degree (1985) and MS degree (1987) in Chemistry from Gakusyuin Univ. In 1987, he joined Canon Inc. and has been engaged in the research of electrophotography as a Senior Engineer. From 2002, he has also been a doctor course student of Dept. of Mechanical Engineering, Waseda Univ. He is working on numerical simulation and measurement of particle dynamics in electrophotography. He is a member of the Imaging Society of Japan, the Society of Powder Technology of Japan, and the Japan Society of Mechanical Engineering.