Numerical Analysis for Behavior of Developer in Magnetic Brush System by the Particles Method

Tetsuyuki Kubota, Hiroyuki Inoue, Yoshio Iino, Jusuke Hidaka*
Fujitsu Limited
Kamikodanaka Nakaharaku Kawasaki Kanagawa, Japan
***Dept. of Chem. Eng. and Materials Sci., Doshisha Univ.**
Kyotanabe, Kyoto, Japan

Abstract

The behavior of developer in a two component magnetic brush system is studied by numerical analysis using the distinct element method which is a category in the particles method. The hybrid model which contains both of the softsphere model and the hard sphere model is proposed. The volume of the numerical calculation is reduced by the hybrid model. The electromagnetic forces and the collisional forces which are derived from the hybrid model are introduced to the force equations. To solve these equations a carrier and a toner behavior are analyzed. The spike phenomena of the carrier particles, the developments to the latent images and their quantitative analysis are obtained by solving the force equations numerically. We obtain the dependence of developed toner mass upon some device parameter using the hybrid model.

Introduction

The development process which is used in the electrophotograph technology such as a laser printer, a copying machine etc. consist of controlling the developer by the electromagnetic forces. Recently it is demanded that the printer is speed up and the printing speed of the printer has became more 20,000 lines/minute. However, the behavior of the developer is a very complicated and it is difficult to observe the detailed behavior of the developer and the physical phenomena of it by the present technology. Therefore, it becomes difficult to predict a developer behavior and to optimize the development process in obtaining the highspeed, high picture qualitization of a device by the measurement and the empirical method.

On the other hand, the large scale numerical analysis of a powder has become possible by the remarkable improvement of the computer performance, recently. Numerical analysis of the powder is being applied in various ground with it and be studied the method and the algorithm of the numerical analysis a lot[1-5]. However, the numerical analysis technology of the powder which is composed of a plural component is not established.

In this paper, we study the numerical analysis technology of the powder that is composed of the plural component of particles in the electromagnetic system. We aim to be possible for numerical analysis of the 2 component development system which are suitable for the highspeed printer. As for this system it is difficult to design the device to obtain the optimal picture quality because the control of the developer is complicated.

In this research we make the new algorithm “Hybrid model” for high speed numerical analysis of the powder which is made by two kind of species and estimate the feature of the developer by applying the hybrid model.

Numerical Powder Simulation

The method called Distinct Element Method(DEM) is used in the numerical analysis of a powder generally[1]. DEM is the method to solve the powder behavior by calculating the force equations of the individual particle that composes the powder. DEM is used fundamentally in this research.

In this method, the collitional forces between all particles are calculated and it is classified to several kinds which is softsphere model, hardsphere model and so on[1,2]. In this research we make the “hybrid model" to combine the softsphere model and the hardsphere models. We calculate the collisional forces by this mode.

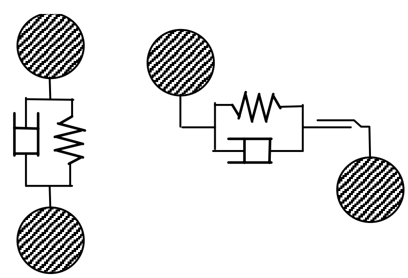


Figure 1 Softsphere model

Softsphere Model

In the softsphere model we look on the particles which constitute the powder as the elastic body (softsphere)[1]. We calculate the volume of dent which is made by the collision between particles and assume that there are spring, viscosity dashpot and friction slider between the particles which touch each other as is shown in Figure 1. We can calculate the collisional forces by this assumption. The coefficients of the spring and the viscosity of the dashpot derive from the Young modulus and Poisson's ratio.

The softsphere model is possible to treat the collisions between many particles accurately and it is suited to calculate the collective behavior of the particles. However it is necessary for the finite differences to divide the time length during the collision into tens step and the time-step must be more small than the time scale of the macroscopical behavior of the powder. Therefore, calculation quantity becomes enormously. If the size of the particle becomes smaller, it needs to make the time-step of more small.

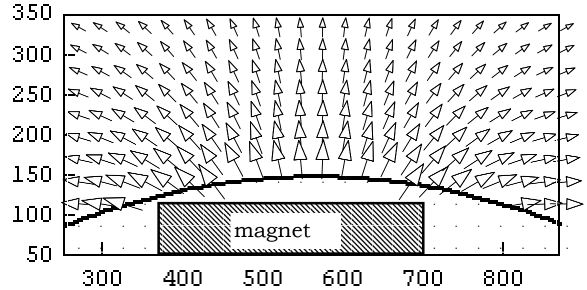
Hardsphere Model

In the hardsphere model, we look on the particles which constitute the powder as a rigid body(hardsphere) and collisional forces between particles are calculated by the momentum preservation law[2]. The coefficient of restitution derives from the Young modulus and Poisson's ratio. The hardsphere model is the one that is suited to calculate the behavior of single particle and is not suited to the calculation of a collective behavior. But using this model, we can make the time-step as the scale of the mean free path of a particle and can be calculating time as one tenth short as it using the soft sphere model.

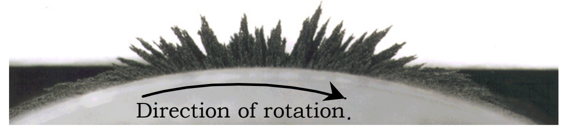
Application to the Developer Analysis of the Numerical Powder Analysis -Hybrid Model-

As for the carrier the collective behavior of the particle is dominant and it is necessary for the calculation of the collisional forces between the carrier particles to use the softsphere model. Because the scale of toner is about 1/10 smaller in comparison with carrier(toner: ones μm, carrier: tens μm), if we use the softsphere model in the calculation of the toner, it is necessary that the time-step is smaller than it which need to calculate the behavior of carrier. Therefore, when we calculate the compound of both with only softsphere model, the calculation time becomes enormous. On the other hand, the mean free path of toner is small sufficiently to the time-step which is used for the calculation of the carrier behavior with the softsphere model. Therefore it is possible that the hardsphere model is applied to the calculation of the toner.

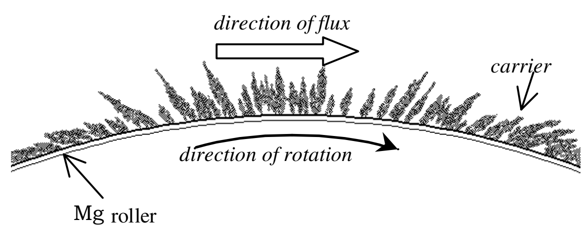
In this research we make the mixed model called a "hybrid model" which is that the hardsphere model is applied to the collision between carrier and toner, softsphere model is applied to the collision between carriers. We neglect the collision between the toner particles because the toner behavior is governed by the collision between the toner and the carrier.



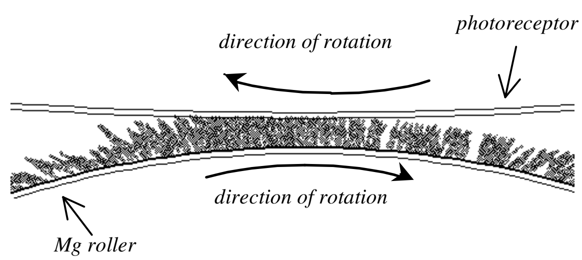
(a) The distribution of the magnetic field on the Mg roller surface.



(b) The photograph of the spike of the carrier particles.



(c) Analysis result of the behavior of carrier at the surface of the Mg roller.



(d)Analysis result of the behavior of carrier in the development region.

Figure 2 Magnetic brush of carrier particles.

Furthermore we introduce the electromagnetic forces which rises from a magnet roller (Mg roller), a photoreceptor and the interaction between particles to the hybrid model. Carrier particle is magnetized by the surrounding magnetic field because it is composed of a strong magnetic substance[6]. The magnetic field that the j th carrier receives is

$$\mathbf{B}_j = \mathbf{B}_M + \sum_{k \neq j} \mathbf{B}_{kj} ,$$

where $\mathbf{B}_M$ is the external magnetic field and $\mathbf{B}_{ij}$ is the magnetic field which rises from the k th particle at the place of the j th particle. The magnetic force that the carrier receives is

$$\mathbf{F}_j = (\mathbf{m}_j \cdot \nabla)\mathbf{B}_j ,$$

where $\mathbf{m}_j$ is the jth particle's magnetic moment which is decided from the external magnetic field and the interaction between the carrier particles.

The carrier particle and the toner particle have an opposite electric charge. The bias is put between the photoreceptor and the Mg roller. This bias is called a development bias. The toner particle receives the electric force which rises from these electric potentials. By the development bias especially, toner adheres to the photoreceptor.

We consider the 2 dimensional plane at where we cut vertically toward the Mg roller axis at the symmetric.

Normalization

In this research, we normalize variables by the parameters as follows, length: the average diameter of a carrier particle (30.0μm), time: the time which the particle does a free fall the distance of the diameter of carrier particle (3.50×10^{-3}s), mass: the average carrier particle's mass (5.20×10^{-10}kg), magnetic field: the maximum magnetic field that rises from the magnet in the Mg roller (0.107T), electric charge: the electric charge that the toner particle is holding (2.19×10^{-15}C).

Behavior of Carrier

The analysis result of the behavior of the carrier particles is shown in Figure 2. The vector plot of the magnetic field at the surface of the Mg roller is shown in Fig. 2(a). The photograph of the spikes of the carriers are shown in Fig. 2(b). In this photograph, the Mg roller rotates clockwise. We can see that the carrier particles form the shape of spikes along the magnetic force line. In Fig. 2(c), the result of the numerical analysis of the carrier particles is shown. We obtain numerically the phenomena that carrier particles form the spikes along the magnetic force line from the Mg roller as the photograph. The behavior of carrier in the development region which is obtained by the numerical analysis is shown in Fig. 2(d). The spikes scrape against the photoreceptor.

Numerical Analysis of Development

In this section, we describe the numerical analysis of the toner behavior that is obtained from the hybrid model. The profile of the electric potential between the Mg roller and the photoreceptor is shown in Figure 3(a). The photoreceptor and the Mg roller rotates clockwise. The potential well is formed on the surface of the photoreceptor, it is designated on Fig. 3(a) as the brace. The electric potential changes with the rotation of the photoreceptor, because it rises from the latent image that is formed on the photoreceptor.

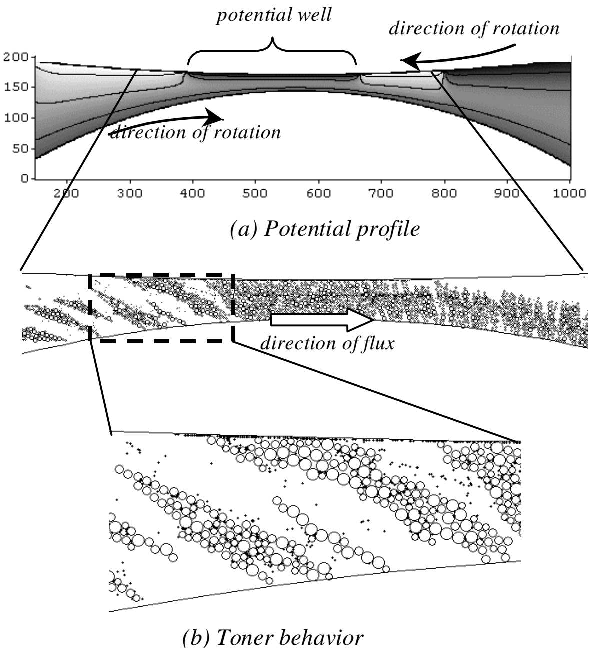


Figure 3 The behavior of toner

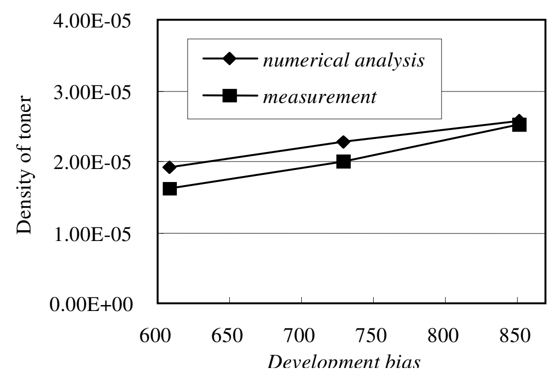


Figure 4 Dependence of the developed toner mass upon the development bias.

Actual number of toner particle, which adheres to a carrier, on the average is estimated as follows, about twenty toner particles adhere to a carrier particle. However, we assume that two toner particles are adhering to a carrier in consideration of the calculation time of the computer. Also, we assume that a toner particle has +1 electrification quantity and a carrier particle has –2 as the charge of whole developer becomes neutral.

In Fig. 3(b), the black points and white circles show the toner and the carrier, respectively. The diameter of the toner particles in Fig. 3 is expanded to 5 times to make it clearly. The developer is conveyed clockwise by the Mg roller. We obtain the phenomena that the toner, which adheres to the carrier in the developer, adheres to the

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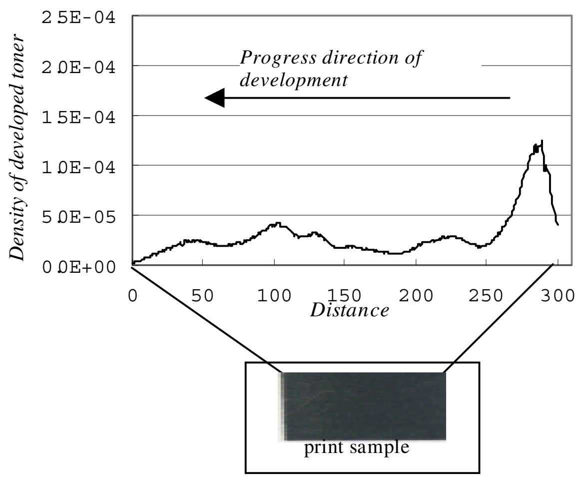
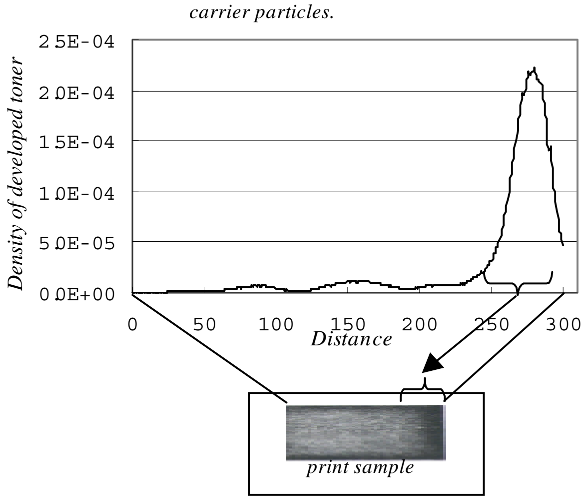
photoreceptor by the electric force from the development potential.

Developed Toner Mass

The dependence of the developed toner mass upon the development bias is shown in Figure 4. In this calculation we assume the length of latent image is infinity. We can see that the developed toner mass increases with the increment of the development bias. The dependence obtained by calculation is as same as it obtained by the measurement. The average difference between the result of the calculation and the measurement is about 12%.



(a)Tthe electric charge leaks from the carrier particles.

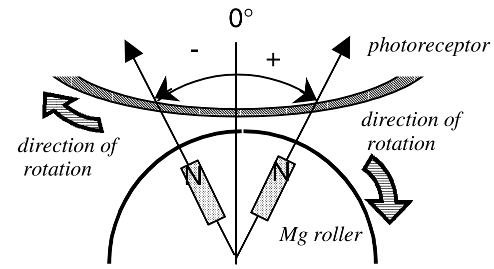


(b)The electric charge does not leaks from the carrier particles.

Figure 5 Distribution of developed toner.

Distribution of Developed Toner

Two graphs in Figure 5 show the density distribution of the developed toner which is obtained by the calculation. We can see that the toner density increases in the edge part of the toner image. It is caused that the toner which adheres to the photoreceptor is drawn to the edge by the counter charge. The electric charge, which the carrier particle holds, leaks while going through the development region. If there is much leakage, the quantity that toner is accumulated to the edge decreases and the toner adheres more evenly. An actual printing samples that corresponded to each adhesion distribution that is obtained by the calculation is shown in Fig. 5.



Difference of the magnet in the Mg roller

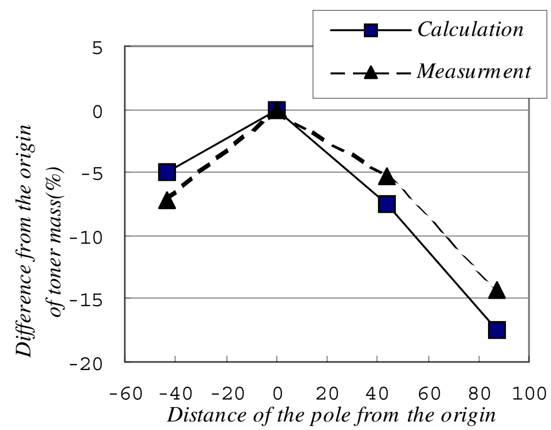


Figure 6 Change of the developed toner mass to the pole position.

Change of Pole

The dependence of the developed toner mass upon the position of the magnet in the Mg roller is shown in Figure 6. The origin of the magnet is the position where the pole approaches the photoreceptor most. The position of the pole is presented as the movement distance from the origin. The developed toner mass is expressed with the difference from the toner mass at the origin. We obtain the results that when the pole is moved from the origin, the developed toner mass decreases. We also obtain the same result by the measurement.

Conclusion

We study the numerical analysis technology of the developer behavior in 2 component development method which is used mainly for a highspeed electrophotograph printer. This method uses the developer that is the compounds of two kinds of the powder. The feature of this developer is that the scale of the toner particle is about 1/10 smaller in comparison with the carrier particle. The

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softsphere model is applied generally in the numerical analysis of a powder. However if the softsphere model is applied to the such powder simply, the calculation quantity becomes enormous. Therefore in this research we make the hybrid model which is made up of the softsphere model and the hardsphere model. By combining a hybrid model and electromagnetic forces we can analyze the behavior of developer in reasonable time.

In this paper we study the dependence of the developed toner mass upon some device parameter using the hybrid model. The developed toner mass increases with the increment of the development bias. When the pole is moved from the origin, the developed toner mass decreases. We obtain the same results by the measurements.

References

1. P. A. Cundall, etal., *Geotechniqu*e, **47**, 29 (1979)
2. K. Nanbu, *J. Phys. Soc. Jpn.*, **49-5**, 2042 (1998).
3. C. P. C. Prado, etal., *Physical Review* A, **45**, 665 (1992).
4. R. A. Gingold, etal., *Mon. Not. Astro. Soc.*, **46**, 429 (1982).
5. M. Kachi, etal., *Japan Hardcopy* ‘97, 1997 (1982).
6. R. S. Paranjpe, etal. *:J. Appl. Phys.*, **60**, 418 (1986).

Biography

Tetsuyuki Kubota is a Engineer of Fujitsu Limited. He received Doctor’s degree in Science(1998) to study the theoretical and numerical plasma physics from the Kyushu University. He has studied about the numerical analysis technology since 1998.