Electrophotographic Simulation Technology

Takuya Goto Kazuteru Kurihara

Demand for printers and copy machines that use electrophotographic systems has been increasing rapidly in recent years. With the colorization of printing devices, not only are electrophotographic systems increasing in their application for document printing in offices, but also for DTP and POP printing. Amidst all of this the performance of devices, from which high speeds and extended definition are required, is becoming more advanced as well.

Printing devices of the electrophotographic system use micro particles 5 to 10 μm in diameter called toners that are charged by friction and form an image using electrostatic force. Although extremely accurate control for accelerating to high speeds and an extension of the definition to a higher image quality is required, many aspects of toner particle behavior are still not clarified, such as friction charging. For this reason, it is necessary to extract parameters based on experience and know-how for development and to repeatedly experiment for optimization. Shortening the development time is essential for commercializing the required functions on time.

Consequently, we are clarifying the underlying principles using numerical analysis and are proceeding with the building of a simulation tool that will be useful for development. This is now being reported as our efforts have recently reached a level where it is possible to reproduce actual phenomena.

Summary of printing process

A summary of the printing process using the electrophotographic method is introduced. **Fig. 1** is a schematic diagram of a printing cartridge. The individual processes of printing include electrostatic charging, exposing, developing, transferring, fusing and cleaning.

The electrostatic charging process involves an even application of an electrical charge on the surface of the photosensitive drum by applying voltage on the charging roller.

The exposing process involves irradiating light that corresponds to the image signals sent from the high definition LED printhead on the surface of a photosensitive drum to form an electrostatic latent image.

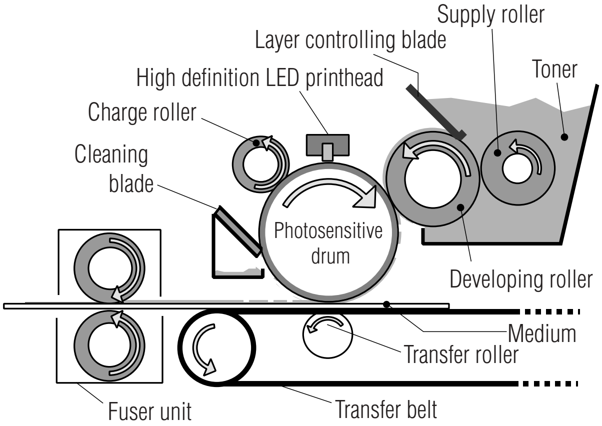

Fig. 1 Schematic diagram of printing process

The developing process firstly involves friction charging of the toner from friction between the supply and developing rollers. The developing roller and supply roller are both impressed with voltage to ensure the attraction of toner on the developing roller. Toner fed by the developing roller is retained on the roller's surface and used to form a thin layer when it passes through the point of contact with the layer controlling blade. The toner is electrically charged here as well by the friction between the layer controlling blade and the developing roller. Furthermore, the toner that formed into a thin layer is transferred by the rotation of the developing roller to the point of contact with the photosensitive drum. Electrical fields are formed so that toner is transferred onto the photosensitive drum at the portion between the photosensitive drum and developing roller on which light is irradiated in the exposing process, whereas toner is retained on the developing roller for portions to which light has not been irradiated.

Toner developed on the photosensitive drum is transferred onto a medium by electrostatic force in the transferring process. The aforementioned operation is performed sequentially for four colors, black, yellow, magenta and cyan, to form a color image on the medium.

The fusing process involves the fusing of toner on the medium using heat and pressure to fuse and fix it.

The cleaning process involves sweeping off the small amount of toner residue left on the photosensitive drum that was not transferred onto the medium during the transferring process.

This report provides analyses on the segment formed by the toner layer during the developing process and analyses on the cleaning process.

Simulation by distinct element method

The method used for simulation is called Distinct Element Method (DEM). The distinct element method is used to simulate the behavior of the particle layer by tracing the movement of individual particles (toner particles in this case) based on an equation of motion.

The Voigt model, shown in **Fig. 2,** was used as a model for the contact force of particles1).

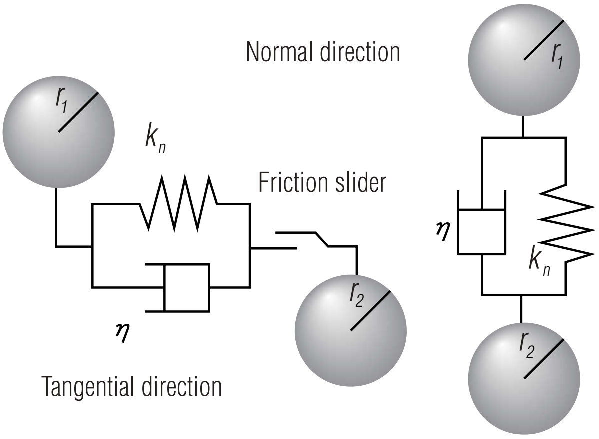

Fig. 2 Voigt model

The Voigt model expresses an elastic repulsion force in the normal and tangential directions with respect to the contact surface, the dissipation of energy due to contact deformation as well as sliding and frictional forces for the tangential direction using the basic elements of mechanics, such as a spring, dashpot and friction slider.

First of all, the force f_t, which is applied to a single toner particle, can be obtained by the formula:

$$f_t = f_o + f_e + f_i + f_v$$

Other than the external force f_o, which is applied on the toner at impact, the coulomb force f_e, received from the surrounding electrical field, along with adhesive forces, such as the van der Waals force f_v, and the image force f_i, have been considered regarding the toner.

If the mass of the particle is m and its position is x and y, while the time is t, then the following relationships apply:

$$m\frac{d^2x}{dt^2} = \sum f_x$$

$$m\frac{d^2y}{dt^2} = \sum f_y$$

The f_x and f_y mentioned here are forces applied to particles in their respective directions. Furthermore, since rotational movements occur with these particles, it is also necessary to obtain the force due to the moment of inertia. If the moment of inertial is I and the momentum in the counterclockwise direction about the center of gravity of the particle is M, while the angular momentum is ω, then we have the following relationship:

$$I\frac{d\omega}{dt} = \sum M$$

By solving the aforementioned equations of motion through numerical calculations, it is possible to calculate the ever changing movement of toner particles.

Toner layer forming simulation

Simulation for the toner layer formation of the non-magnetic monocomponent developing method is introduced.

The process in which a thin layer of electrostatically charged toner on the developing roller forms is an extremely important process that greatly influences the print quality. If the toner layer formed in this process is not stabilized the printing density does not stabilize and nonconformity is evident with the reproduction of color, particularly when color images are printed.

Various factors, such as electrostatic charges or the cohesiveness of the physical characteristics of toner, the physical characteristics, shape and installation setup of the layer controlling blade, as well as the friction coefficient or the surface roughness on the physical characteristics of the developing roller, can be cited as parameters that impact the thin layer formation of toner. We built a simulation model for studying these parameters. This model is shown in **Fig. 3**.

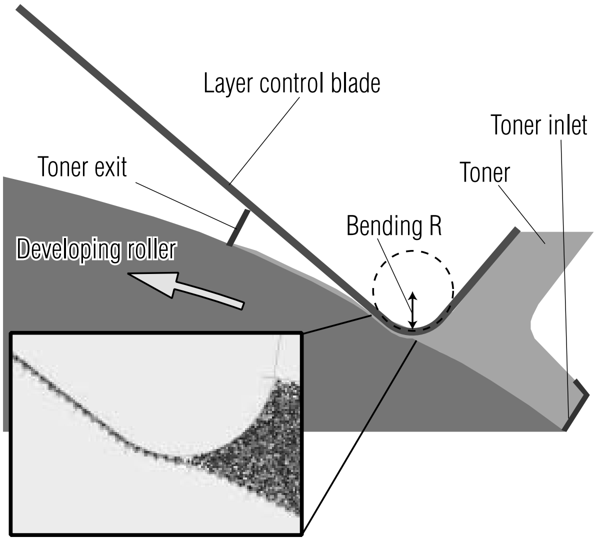

Fig. 3 Layer formation simulation model

The layer control blade in the model is formed in an L-shape with a metal plate and its edge segment pressure is welded onto the developing roller. The curvature radius of the edge segment shall be R. The developing roller is comprised of rubber molded in a cylindrical shape around the metallic shaft. The surface of the developing roller maintains roughness and the average roughness shall be R_z. The compressive force, where the layer control blade and developing roller meet, as well as the deformation of shape at the contact points, were derived from a structural analysis using the finite element method. The developing roller turns in the direction of the arrow shown in the figure and the inlet of the toner is located on the upstream side of the rotating direction and this is where the toner is supplied. An exit for the toner was set up on the downstream side of the rotating direction, beyond the region where the layer control blade and developing roller come into contact. Once the toner leaves the exit, the toner can be supplied through the inlet again, while retaining its history.

Furthermore, the friction charging in the toner particles shall follow the law described below:

- When toner particles experience friction with the layer control blade or developing roller the electrical charge, which is proportional to the friction distance, accumulates.
- Once the amount of accumulated electrical charge reaches the prescribed charge saturation, no further electrical charge will be stored.

Fluctuations in the thickness of toner layer and changes in the charged amount of toner to be passed through the layer control blade without being consumed were simulated using the aforementioned model. The process of the cycle comprised of the toner passing out of the exit, supplied through the inlet and reaching the exit once again is considered to be one rotation of the developing roller. The results depicted with the number of rotations represented along the horizontal axis are shown in **Figs. 4** and **5**.

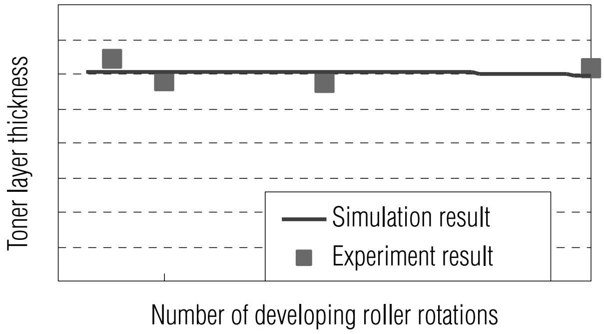

Fig. 4 Fluctuation in toner layer thickness

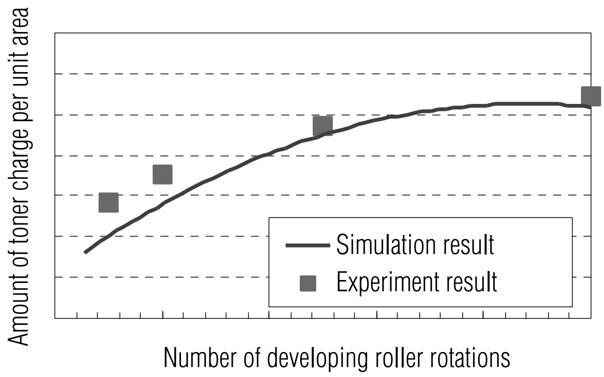

Fig. 5 Fluctuation in toner charge amount

Plotted points in **Figs. 4** and **5** are the result of experiments equivalent to the simulation model. Both the toner layer thickness and charge amount matched well with the results from the simulation and the validity of the model was verified.

Next, parameters considered to be impacting the thin layer formation were studied. For this the toner layer thickness was simulated in two instances, one with the increased curvature radius R of the edge segment on the layer control blade and the other with the increased surface roughness R_z of the developing roller. The results of these simulations, along with the results of an experiment conducted with equivalent conditions, are shown in **Fig. 6**.

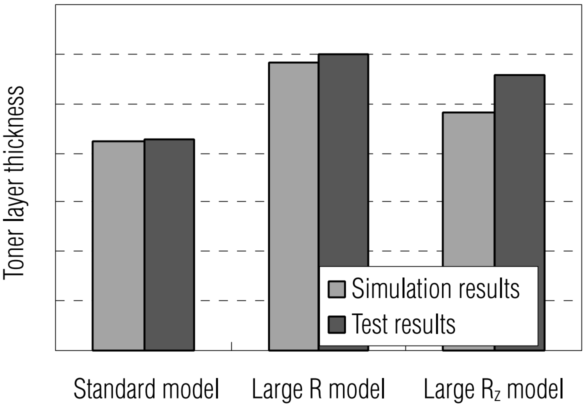

Fig. 6 Parameter study

Fig. 6 shows that when the curvature radius R of the edge segment of the layer control blade is increased the toner layer becomes thicker. Furthermore, the toner layer also becomes thicker when the surface roughness R_z of the developing roller is increased. The results of both simulations and experiments indicate similar trends, thus we can consider the model to be a simulation model adequate for use in considering parameters during the development.

Cleaning simulation

The simulation of a cleaning process using a rubber blade is introduced.

Due to demand for higher image quality printers, reductions in the diameter and conglobation of the toner particles are drawing attention as effective technologies to respond to such demand. Reducing the diameter and conglobation of the toner particles make it possible to reproduce finer regions in an image. However, a deterioration tendency in the blade cleaning characteristics becomes evident due to the implementation of these steps to improve the printing image quality. The experiment results relating to the impact of the toner conglobation on the blade cleaning characteristics are shown in **Fig. 7**.

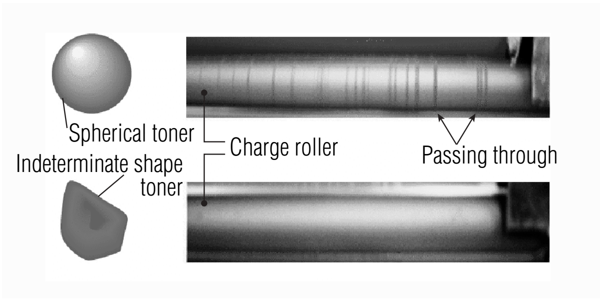

Fig. 7 Continuous printing test results

Two types of toners with different shapes were used. One is a toner of a spherical type while the other has an indeterminate shape. On the right are photographs of charge rollers after text was continuously printed. Spherical toners slipped through the cleaning blade and became adhered to the charge roller. When toner became attached to the charge roller it triggered faulty electrostatic charging of the photosensitive drum, which caused deterioration in the printing quality as printing was continuous. When a similar kind of endurance test was performed with toners of indeterminate shapes, they did not slip through the blade and deterioration to the printing quality did not occur over time.

When toners with different shapes are used in this manner a gap in the cleaning performance arises and the image quality is impacted.

For this reason, the movement of toners and blade were investigated to clarify the process of the blade cleaning and a model for a cleaning simulation was built to study the causative factors for the occurrence of faulty cleaning. This model is shown in **Fig. 8**.

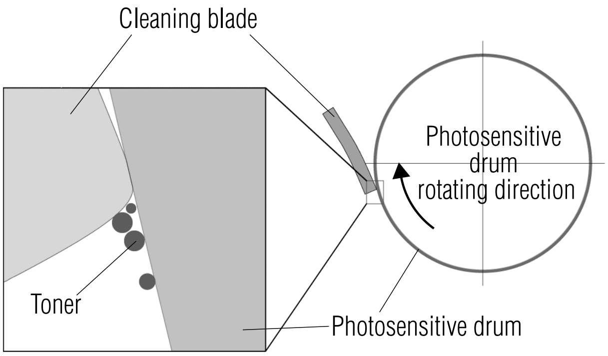

Fig. 8 Cleaning simulation model

Other than the movement of toner the movement of the blade is also important in blade cleaning. Since the rubber blade is in contact with the rotating photosensitive drum, sticking and slipping movements occur, which causes vibrations repeatedly at the tip of the blade. For this reason, rubber blade movements were structurally analyzed for each temporal step using the boundary element method, with consideration for the force applied by the toner.

In the simulation, the toner was supplied to the leading edge segment of the blade by the rotation of the photosensitive drum. An evaluation was conducted to determine whether or not supplied toner slips through the edge of the blade. Results of the simulation are shown in **Figs. 9** and **10**.

TIPS Basic Glossary

DTP(desktop publishing)

Known as desktop publishing or tabletop publishing in Japan. Editing and arranging printed matter with the use of computers.

POP(point of purchase advertising)

Advertisement media inscribed with information regarding prices or sales items, used at the storefronts of supermarkets and shops.

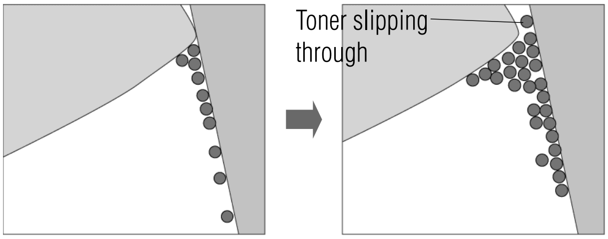

Fig. 9 Spherical toner simulation

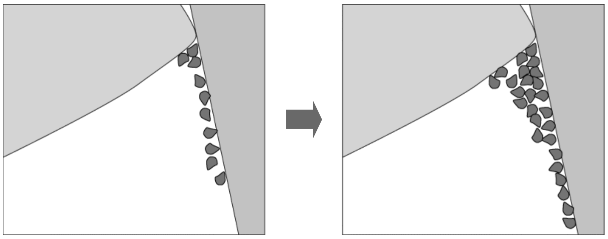

Fig. 10 Indeterminate shape toner simulation

Similar to the results of the experiments the indeterminate shape toner did not slip through the blade while the spherical toner did.

From the above results we can conclude that the simulation of the cleaning process is reproducing the actual phenomenon.

Conclusion

Electrophotographic simulation of Oki Data has been introduced thus far. We intend to establish analysis led design methodologies by using such tools to realize a shortening of the development time in the future.

References

1) The Society of Powder Technology, Japan (Editing): Introduction to Fine Particle Simulations, First Edition, pp. 29-80, Sangyo Tosho Publishing, 1998.

Authors

Takuya Goto: Oki Data Corporation, NIP Business Div., Process Development Center, Process Development Dept.-2, ID Development Team-6.

Kazuteru Kurihara: Oki Data Corporation, NIP Business Div., Process Development Center, Material Engineering Development Dept., Material Engineering Team-1.