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Simulation of Electrophotographic Process

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Abstract

An LED printer prints by an electrophotographic recording system using static electricity. Since the observation of static electricity is difficult, an analysis by simulation is effective.

This paper shows the simulation method for each process of the electrophotographic recording system, and the results of simulating exposure and transfer processes with the intention to improve resolution. This simulation makes it possible to develop a high resolution electrophotographic process in a short period of time

1. Introduction

An electrophotographic printer consists of six processes: charging, exposure, developing, transfer, fusing and cleaning[1].

For printing, charged toner, which is a coloring agent, is selectively transferred to the recording paper primarily by static electricity.

Recently electrophotographic printers are increasing in resolution, from 300 dpi to 600 dpi and to 1200 dpi. In the case of 1200 dpi, the developing process with an extension of conventional technology, such as for 600 dpi, is becoming difficult. This is because the thickness of the photoconductor and toner layer can be decreased in proportion to resolution in terms of charging performance and recording density.

As resolution increases, measuring static electricity operating in a micro area is becoming progressively more difficult. As a consequence, analyzing an electrostatic field in detail, which is the generation source of static electricity, by simulation is becoming indispensable for the development of electrophotographic printers.

This paper reports on the simulation method for each process of electrophotographic printers and the result of analyzing the exposure and transfer processes to implement high resolution.

2. Electrophotographic process simulation

The LED printers of Okidata implement the electrophotographic process by applying an electrostatic phenomena to all processes other than fusing. For example, a magnetic brush development method that utilizes a magnetic force is generally used for the development process, but Okidata has been using a non-magnetic one component development method, which uses only static electricity[1,2].

A mechanical blade method is the commonly used method for the cleaning process, but we have been using electrostatic cleaning by a semiconductive rubber roller, where voltage is applied[1].

In the charging and transfer processes, we have been using a contact method by a semiconductive rubber roller where voltage is applied, rather than a corona discharge[1]. Therefore in an electrophotographic process simulation, we analyzed the electrostatic field, the orbit of charged particles, and steady / non-steady state current by a finite element method. The semiconductive rubber roller has an electrical nature to exhibit nonlinear electric resistance in a high voltage region. This nonlinearity also must be considered in this process.

2.1 Charging process simulation

The photoconductor is charged by microspace charging, directly contacting the DC voltage applied semiconductive rubber roller on the photoconductor. This phenomena is clearly explained by Paschen's Law[3].

In simulation, we used a 3 layer model of a semiconductive rubber roller, air and photoconductor, with thickness, dielectric constant and impedance as the physical parameters.

2.2 Developing process simulation

In the developing process, the negatively charged toner is transferred from the conductive rubber roller to the photoconductor by the latent image potential created on the photosensitive layer during the charging and exposure processes, and by the electric field generated by the bias voltage applied on the conductive rubber roller transfer.

Figure 2 shows the simulation model that has a 3 layer structure of the conductive rubber roller, toner and photoconductor. We used the analysis results of exposure simulation as the initial values, and thickness, dielectric constant, and the surface and volume charge distribution density as the parameters.

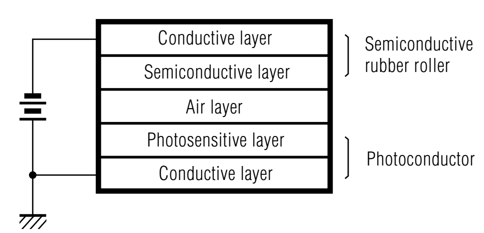

Figure 1: Charging model

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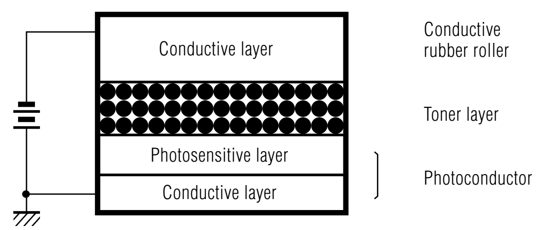

Figure 2: Developing model

2.3 Cleaning process simulation

In the cleaning process, the electric field generated by the voltage applied to the semiconductive rubber roller transfers residual toner on the photoconductor to the semiconductive rubber roller. Here we used simulation models similar to those of the developing process.

2.4 Exposure process simulation for increasing resolution

The exposure system of an LED printer is an LED head, which consists of an LED array and rod lens array[4]. Electrostatic patterns are created on the photoconductor by the exposure patterns from this LED head.

As resolution increases, it is important for the exposure process to optimize micro electrostatic patterns which are determined by the emitting profiles of the LED, the resolution of the LED based on the rod lens array, and by the photosensitivity characteristics of the photoconductor.

1. Simulation method

Figure 3 shows the result of measuring the light intensity distribution when light is irradiated from one LED element to the photoconductor. Light intensity distribution E (x) is approximated by the sum of two Gaussian distributions as shown in formula (a).

$$E(x) = a \times f(x, y, \sigma_1) + b \times f(x, y, \sigma_2) \ldots (1)$$

a, b: constants

σ1,σ2: standard deviation

An exposure pattern is generated from composite waveforms of these light intensity distributions. Figure 4 shows an example of an exposure pattern where waveforms are synthesized at a basic pitch of 1200 dpi resolution.

Then based on this exposure pattern and analysis result of photoconductor surface potential obtained from the charging process simulation, the latent image potential on the photoconductor is analyzed using the photosensitivity characteristic of the photoconductor. The resolution evaluation method that we used is the Modulation Transfer Function (MTF). MTF is given by the following formula if MAX and MIN are known by the exposure pattern at the basic pitch in Figure 4.

$$MTF = \frac{MAX - MIN}{MAX + MIN} \times 100(\%) \cdots\cdots\cdots (2)$$

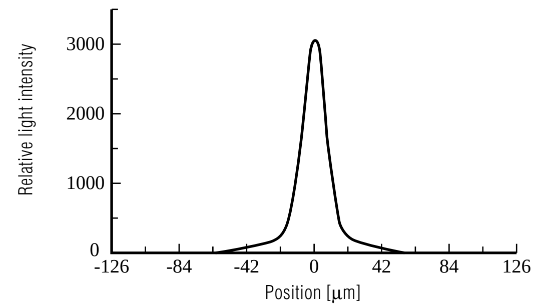

Figure 3: Light intensity distribution

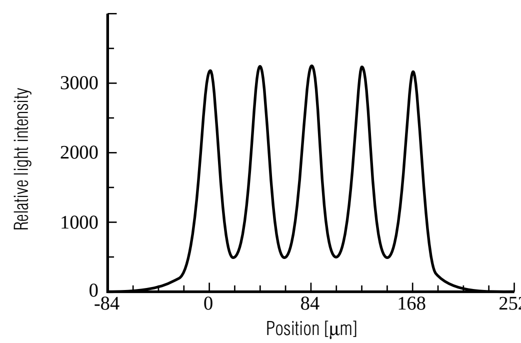

Figure 4: Exposure pattern

The MTF value was changed by changing σ1 and σ2 of formula (1) using the correlation coefficient determined by experiment.

2. Resolution and electrostatic pattern

Figures 5 and 6 show the results of analyzing the exposure pattern (dot, line) when MTF of the LED head is 70 and 90%, and the latent image potential that corresponds to the electrostatic pattern. In this result, the latent image potential of the line pattern is smaller than that of the dot pattern. If MTF is high, as shown in Figure 6, the latent image potential of the line pattern becomes closer to that of the dot pattern, decreasing the latent image potential difference depending on the exposure pattern. This is probably because a high MTF makes light intensity distribution sharper, and decreases the influence on peripheral dots as the exposure patterns becomes more dense, such as in a line.

3. Effect of simulation

It is difficult to directly measure the micro electrostatic patterns created by the exposure processing using a surface electrometer. Therefore we compared analysis results and experiment results of the toner image on the photoconductor created by the developing process, and evaluated the effectiveness of simulation.

Figure 7 (a) shows the result of analyzing toner images created on the photoconductor, using the analysis result

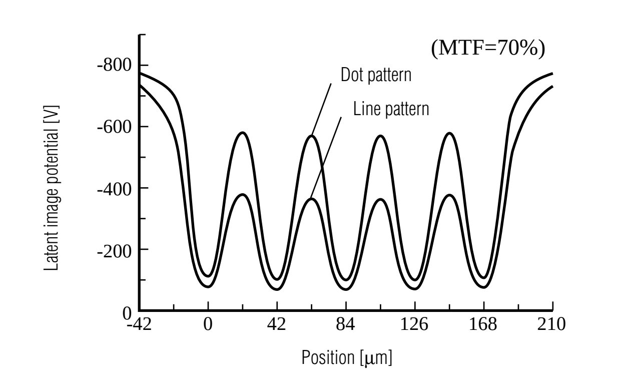

Figure 5: Latent image potential (MTF = 70%)

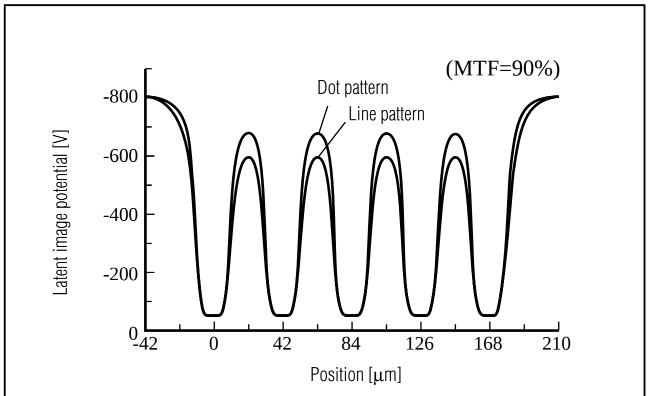

Figure 6: Latent image potential (MFT = 90%)

of Figure 5 for the initial values of developing process simulation, and Figure 7 (b) shows an enlarged photograph of the toner image created on the photoconductor from the experiment.

This simulation largely matched with the experiment result, showing that optimization of parameters required for the exposure process is now possible.

2.5 Transfer process simulation for improving resolution

In the transfer process, the toner image created by the developing process is transferred to recording paper by the transfer electric field generated between the voltage applied transfer roller and the photoconductor[1]. To transfer a toner image at 1200 dpi basic dots (approx. 21 μm width) accurately onto recording paper, the transfer electric field must be linear. However, as shown in Figure 5, a latent image potential difference occurs between the exposed areas and the non-exposed areas in the exposure process. Toner images created by the developing process also have electric charges. For these reasons, the transfer electric field warps.

So we estimated the transfer status of a toner image by analyzing the electric field in the toner layer, and simulated transfer conditions to improve resolution.

1. Simulation method

The electric field between the photoconductor and the transfer roller is simulated using the analysis results of the exposure and development process simulation as initial values, and the charge of the electric line of force is determined. A dot pattern is used for exposure to the photoconductor, and the parameters are resolution, electric charge of toner and transfer voltage.

2. Analysis result and considerations

Figure 8 shows an example of an analysis of an electric line of force between the photoconductor and the transfer roller. Δx in Figure 8 is the change width of the electric line of force which passes through the lower layer of the toner layer on the recording paper side, but does not pass through the top layer of the photoconductor. Also, the electric line of force does not move inside the toner layer linearly, but winds toward the non-exposed area and reaches the photoconductor. since toner is negatively charged, toner moves to the opposite direction along the electric line of force. The electric line of force near the dot center has a long distance to pass through the toner layer, therefore more toner moves to the area near the dot center rather than to the dot center on the recording paper.

As an index to evaluate transferability along with the movement of toner, the change ratio of dot width transferred from the photoconductor to the recording paper (defined as the dot creation ratio) is deter-

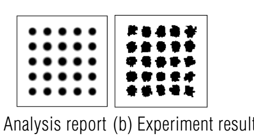

Figure 7: Toner image

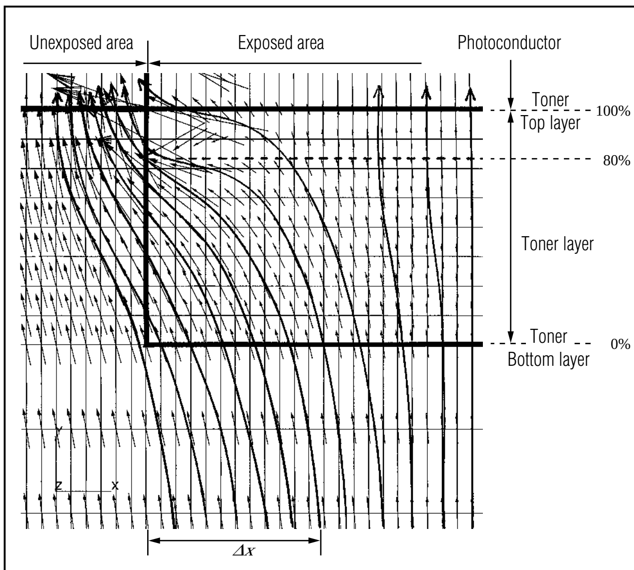

Figure 8: Electric line of force

mined from the following formula.

$$\text{Dot creation ratio} = \left(1 - \frac{\Delta X \times 2}{\text{basic dot width}}\right) \times 100(\%) \cdots\cdots\cdots\cdots\cdots(3)$$

Figure 9 shows the relationship between resolution and the dot creation ratio, with the electric charge of toner and the transfer voltage as parameters. The dot creation ratio decreases as resolution increases, and when the electric charge of toner is high and the transfer voltage is low, as in curve A, one dot at 1200 dpi is difficult to create. This means that a dot becomes smaller than the basic dot width as resolution increases.

When the electric charge of toner is decreased, as in curve B, the dot creation ratio increases, 17% at 1200 dpi. This is probably because the electric field is weakened by charged toner. When the transfer voltage is increased, as in curve C, the dot creation ratio further increases to 67%. This is probably because the increase of transfer voltage relatively decreases the latent image potential difference between the exposed area and unexposed area on the photoconductor.

In this way, optimization of parameters along with increasing the resolution of the transfer process became possible.

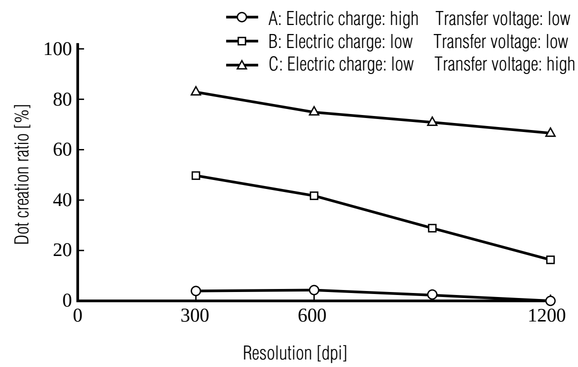

Figure 9: Resolution and dot creation ratio

3. Conclusion

We developed simulations for analyzing an individual electrophotographic process and for analyzing all processes, other than fusing, by connecting the above analysis results in a cascade format.

By using these simulations, optimizing parameters in each process, and optimizing parameters among processes became possible in electrophotographic printer development, and high reliability and high resolution electrophotographic processes could be constructed in a short time.

In the future, we will analyze the optimization of various parameters using this method to implement higher resolution and higher speed.

4. References

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