CASE 34

Development of an Electrophotographic Toner Charging Function Measuring System

Abstract: Through this research we developed a measuring technology for toner particles ahead of designing functions for a developer and a developing device. Here we describe a two-ingredient developer as a typical example. This is a developer that supplies a target amount of charge to a toner particle by mixing a charged particle and a toner particle and charging the toner with friction.

1. Introduction

An imaging method in electrophotography used for photocopy machines or printers is to develop an electrostatic latent image that is transferred onto photosensitive material to obtain an objective image using charged toner particles. Therefore, in designing electrophotographic developer to reproduce an electrostatic latent image accurately, control of the amount of charge of toner particles is a major technical problem. To solve this, a measuring technology for a charging function focusing on individual toner particles, which can be used to design a charging function for toner particles, needs to be established. Since we have realized the importance of developing a measuring technology through this research, we developed the technology ahead of designing functions for the developer and the developing device.

Here, as a typical example, we describe two-ingredient developer. This is developer that supplies a target amount of charge to a toner particle by mixing a charged particle (called a *carrier particle*) and a toner particle and charging the toner with friction. Figure 1 shows an outline of electrophotography. A toner particle is required to have a function, particularly in a developing area. This is a process using a toner's characteristic of being charged.

In a developing area, a toner particle, the particle to be developed (Figure 2), is transferred onto photosensitive material and developed in accordance with the strength of an electric field formed by imaging information between a developing sleeve and the photosensitive material. That is, development is a system of controlling toner particles by the strength of an electric field. Now, since it is expected that an individual toner particle is transferred to a target position and developed according to the strength of an electric field, a constant amount of charge in a toner particle is considered ideal. In other words, the ideal function of a toner particle is that each toner particle has an identical amount of charge. To proceed with the functional design of a toner particle, we need to measure the amount of charge each toner particle and to evaluate the uniformity. In the following sections we discuss optimization of a measuring system.

2. Measuring System and Generic Function

As a measurement of an amount of charge in an individual toner particle, we selected a measuring system based on the E-Spart method, codeveloped by the University of Arkansas and Hosokawa Micron Corporation as a method of measuring the

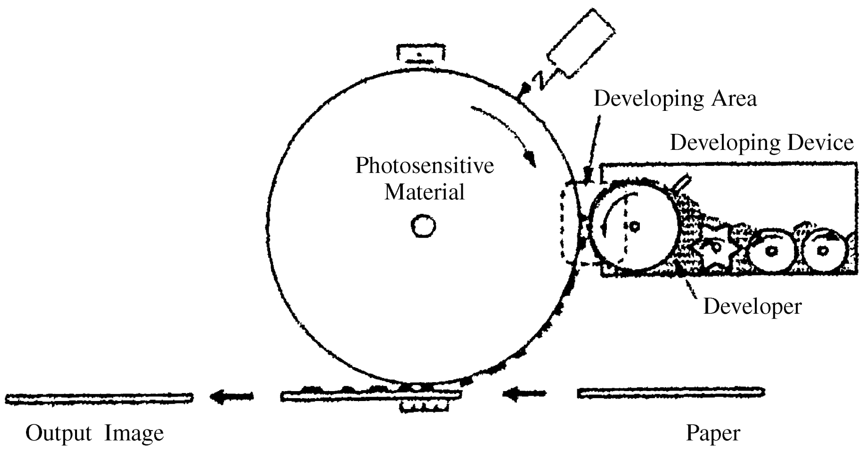

Figure 1
Electrophotography process

distribution of an amount of charge. The measuring system for an amount of charge is composed of a particle supplier to provide toner particles as our objective to be measured, an air blower to remove particles, and a charged amount detector to sense the movement of particles (Figure 3). At the charged amount detector, particles pass through an electric field generated by a pair of electrodes. At the same time, because of an air vibration field formed between the electrodes, together with the electric field, each particle runs through with oscillation. By detecting this particle movement using a laser beam, we can simultaneously measure the amount of charge and the diameter of each particle.

In general, the generic function of a measuring system is regarded as a proportionality between the true value, M, and the measurement, y. However, since it is realistically difficult to prepare the true amount of charge as a signal factor, we need to arrange an alternative signal factor for the true

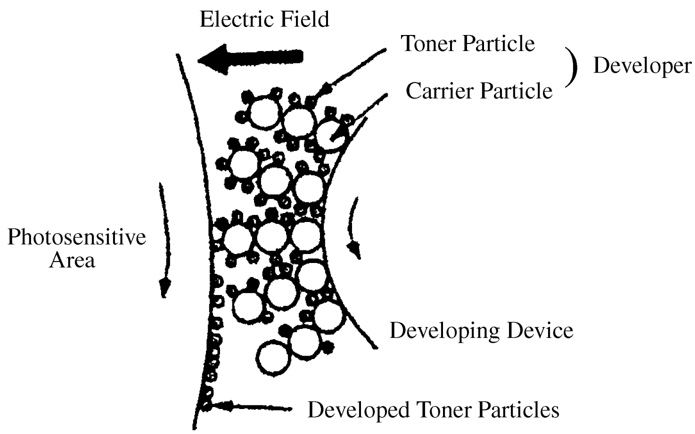

Figure 2
Movement of toner particles in developing area

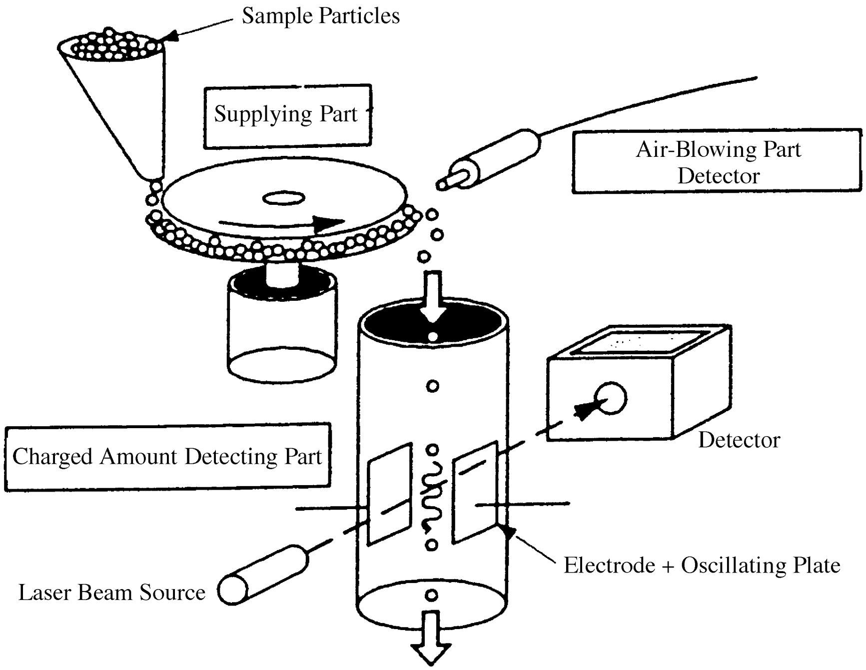

Figure 3
Measuring system for amount of charge

amount. Then, emphasizing cost and simplicity in this research, we studied whether it is possible to conduct the functional design of a charged amount measuring system by taking advantage of existing toner particles with a sufficiently good track record as a signal factor. When we use an actual product as a signal factor level, the reliability of the factor level comes into question. As a result of our thoroughness, an amount of charge per surface area was considered the most stable. Therefore, setting the sum of surface areas of all toner particles to an input, M, and the sum of their charge amounts to an output, y, we defined their zero-point proportional relationship as a generic function. In this case, the surface area of each toner particle was calculated by its diameter on the assumption that it was a perfect sphere.

To select a surface area as a signal factor, we used three different levels with regard to the surface area of a particle:

1. *Signal factor, M:* sum of surface areas of particles (three levels). Because of the difficulty of checking the surface area of a particle during measurement, by taking a measurement for approximately 30, 60, and 90 toner particles, we converted each particle diameter measured into a surface area as a signal factor.
2. *Indicative factor, M**: average amount of charge of a particle (two levels). In this study, as an indicative factor, we chose an average amount of charge of a toner particle with two levels. To cover a practical range of charge amounts, we chose two levels, one for a sufficiently high amount and the other for a sufficiently low amount. As a matter of course, the true value of each amount of charge was unknown.

Since no noise factor is handled here, we performed a split-type analysis.

3. SN Ratio and Sensitivity

Because no error factor was chosen, we could not provide the degrees of freedom of the error through normal calculations of the SN ratio and sensitivity. Thus, we used a split analysis method in our research. This provides a way to calculate an SN ratio and sensitivity for each control factor level. For instance, we show the calculation procedures for the SN ratio and sensitivity of control factor A_1 in Table 1. In this experiment, factor A is assigned to the first column of an L_{18} orthogonal array using the data in experiments 1 through 9, where A_1 was assigned. Now since a surface area as a signal factor M was computed from a number of particles, each experiment had different signal level values.

Total variation:

$$S_T = 216.43^2 + 385.09^2 + \cdots + 112.96^2 + 148.09^3$$
$$= 2{,}896{,}492 \qquad (f = 54) \tag{1}$$

Linear equations:

$$L_1 = (7750)(216.43) + (13{,}269)(385.09) + (18{,}957)(498.32)$$
$$= 16{,}233{,}744$$
$$L_1' = (8440)(95.41) + (12{,}522)(135.99) + (17{,}875)(173.65)$$
$$= 5{,}612{,}121$$
$$\vdots$$
$$L_9' = (7996)(65.42) + (12{,}243)(112.96) + (16{,}032)(148.09)$$
$$= 4{,}280{,}246 \tag{2}$$

Effective divider:

$$r_1 = 7750^2 + 13{,}269^2 + 18{,}957^2 = 595{,}496{,}710$$
$$r_1' = 8440^2 + 12{,}522^2 + 17{,}875^2 = 547{,}549{,}709$$
$$\vdots$$
$$r_9' = 7996^2 + 12{,}243^2 + 16{,}032^2 = 470{,}852{,}089 \tag{3}$$

Variation of proportional term:

$$S_\beta = \frac{(L_1 + L_1' + \cdots + L_9')^2}{r_1 + r_1' + \cdots + r_9'} = 2{,}269{,}031 \qquad (f = 1) \tag{4}$$

Variation of M*χβ between rows:

$$S_{M*\beta} = \frac{(L_1 + \cdots + L_9)^2}{r_1 + \cdots + r_9} + \frac{(L_1' + \cdots + L_9')}{r_1' + \cdots + r_9'} - S_\beta$$
$$= 582{,}097 \qquad (f = 1) \tag{5}$$

Variation of differences between proportional terms of indicative factor:

$$S_{\text{row}(M*\beta)} = \frac{L_1}{r_1} + \frac{L_1'}{r_1'} + \cdots + \frac{L_9'}{r_9'} - S_\beta - S_{M*\beta}$$
$$= 31{,}846 \qquad (f = 16) \tag{6}$$

Error variation:

$$S_e = S_T - S_\beta\ S_{M*\beta} - S_{\text{row}(M*\beta)} - S$$
$$= 13{,}518 \qquad (f = 36) \tag{7}$$

Error variance:

$$V_e = \frac{S_e}{36} = \frac{13{,}518}{36} = 376 \tag{8}$$

SN ratio:

$$\eta_{A1} = 10 \log \frac{[1/(r_1 + r_1' + \cdots + r_9')](S_\beta - V_e)}{V_e}$$
$$= -61.2 \text{ dB} \tag{9}$$

Sensitivity:

$$S_{A1} = 10 \log \frac{1}{r_1 + r_1' + \cdots + r_9'} (S_\beta - V_e)$$
$$= -35.5 \text{ dB} \tag{10}$$

For other control factor levels, we computed the SN ratios and sensitivities by following the same procedure.

4. Optimal Configuration and Confirmatory Experiment

Using an L_{18} orthogonal array, we selected as control factors the eight factors shown in Table 2. Figure 4 shows the response graphs.

When an optimal configuration was selected, we prioritized levels with a high SN ratio. However, for some factor levels, we selected those that provided easier handling of equipment. We cannot calculate

Table 1
Data in each experiment under control factor A_1 (M, μm²; y, fC)

No.		Experimental Data				Effective Divider	Linear Equation
1	M_1^* (large charge amount)	M	7,750	13,269	18,957	r_1	L_1
		y	216.43	385.09	498.32	(595,496,710)	(16,233,744)
	M_2^* (small charge amount)	M'	8,440	12,522	17,875	r'_1	L'_1
		y'	95.41	135.99	173.65	(547,549,709)	(5,612,121)
⋮	⋮					⋮	⋮
9	M_1^* (large charge amount)	M	5,387	12,337	18,259	r_9	L_9
		y	140.38	301.42	455.37	(363,931,139)	(9,442,478)
	M_2^* (small charge amount)	M'	7,996	12,243	16,032	r'_9	L'_9
		y'	65.42	112.96	148.09	(470,852,089)	(4,280,248)

the process average obtained through split-type analysis. To estimate gains, by adding up each gain for each control factor, we need to compute a sum of gains directly. As shown in Table 3, according to the confirmatory experiment, we achieved fairly good reproducibility in gain. Using an optimized measuring system, we can expect that our design of the charging function of toner particles is sufficiently streamlined.

Next, we calculated the cost/benefit ratio on the assumption that the total cost/benefit advantage earned through our measuring technology could be attributed to an improved inspection process. First, the functional limit of a charge amount based on the current inspection method Δ_0 is

$$\Delta_0 = 7.5\ \mu\text{C/g} \tag{11}$$

When the amount of charge exceeded the func-

Table 2
Control factors and levels

Control Factor	Level 1	Level 2[a]	Level 3
A: particle supplier condition 1	Standard − 5	Standard	—
B: particle supplier condition 2	6	9	12
C: air-supplying condition 1	Standard − 5	Standard	Standard + 5
D: air-supplying condition 2	0.2	0.3	0.4
E: air-supplying condition 3	1	3	5
F: particle supplier condition 3	5	20	35
G: detector condition 1	2	3	4
H: detector condition 2	5	10	15

[a] Current level.

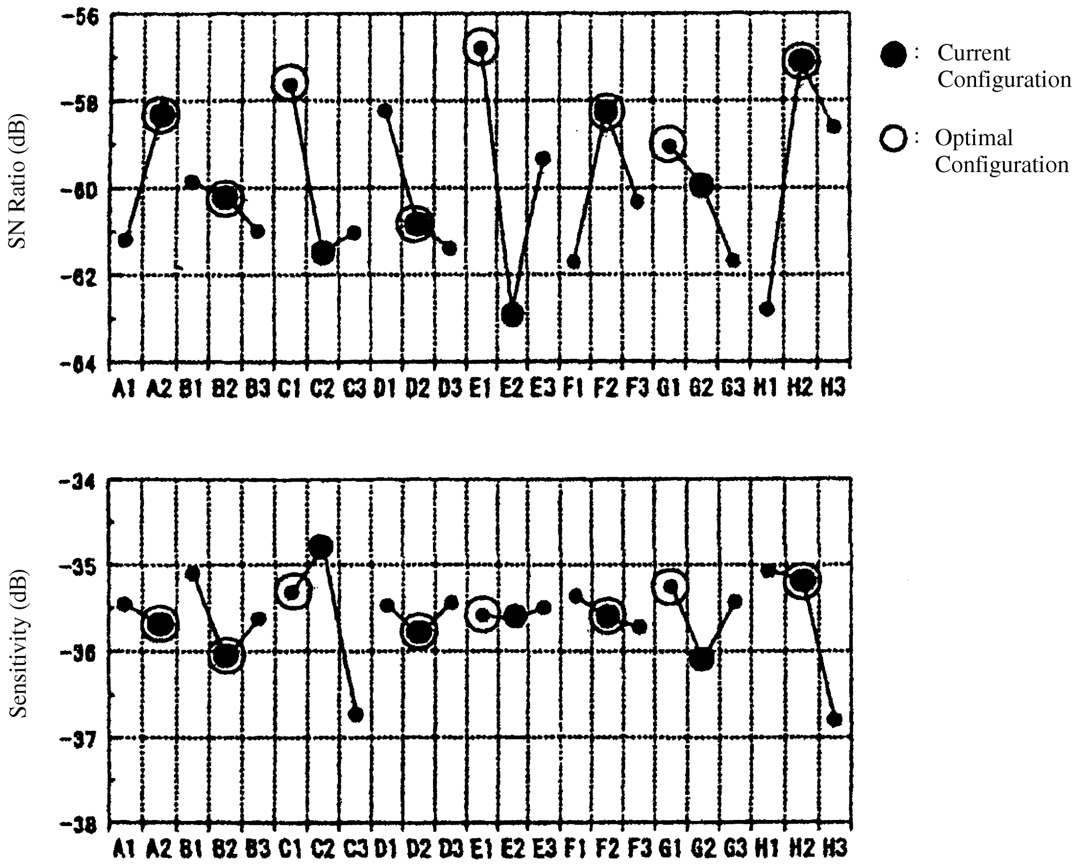

Figure 4
Response graphs

Table 3
Confirmation of SN ratio and sensitivity (dB)

	SN Ratio		Sensitivity	
Configuration	**Estimation**	**Confirmation**	**Estimation**	**Confirmation**
Current	—	−57.7	—	−36.5
Optimal	Value at current configuration, +10.8	−48.7	Value at current configuration, +0.4	−37.7
Gain	+10.8	+9.0	+0.4	−1.2

tional limit, the production lot of developer was discarded. Therefore, the cost of developer per se results in a loss, A_0. The loss function, L_0, is as follows:

$$A_0 = 100 \text{ million yen/lot} \quad (12)$$

$$L_0 = \frac{A_0}{\Delta_0^2}\sigma_0^2 = \frac{100 \text{ million yen}}{7.5^2}\sigma_0^2$$
$$= 17{,}778\sigma_0^2 \quad (13)$$

Assuming that the sensitivity can be adjusted, we obtained the following from the confirmatory experiment:

$$\frac{\sigma^2_{\text{optimal}}}{\sigma^2_{\text{current}}} \approx 0.0956 \quad (14)$$

Since we know that the current inspection of amounts of charge has the error variance, σ_0^2 = approximately 0.8, the cost benefit per lot is as follows:

$$\Delta L = L_{\text{current}} - L_{\text{optimal}}$$
$$= (17{,}778)(0.8)(1 - 0.0956) \approx 12{,}863 \text{ yen/lot} \quad (15)$$

Now, setting the annual production volume of developer to 500 lots, the annual cost benefit is

$$(12{,}863 \text{ yen/lot})(500 \text{ lots/year})$$
$$= \text{approximately } 6{,}430{,}000 \text{ yen/year} \quad (16)$$

Reference

Kishio Tamura and Hiroyuki Takagiwa, 1999. Optimization of a charge measuring system for electrophotographic toner focused on each individual particle. *Quality Engineering*, Vol. 7, No. 5, pp. 47–54.

This case study is contributed by Kishio Tamura.