CASE 21

Development of High-Quality Developers for Electrophotography

Abstract: We have used Taguchi's methods in the development of developers and toners with good results. Here we report on the development of a high-quality developer. The developer formulation and production conditions were studied as control factors. The environmental conditions during the carrier and toner mixing stages were considered as noise factors. From this study, a developer demonstrating only a small fluctuation in triboelectrical charge to environmental change and deterioration was obtained.

1. Introduction

An electrophotography process consists of (1) electrical charge, (2) exposure, (3) development, (4) transfer/separation, and (5) fixing (Figure 1). In developing this electrophotography process, we utilized the magnetic brush development method with a two-component developer comprising toner and carrier (called simply *developer*). In magnetic brush development, the carrier, magnetic material, is held on a sleeve, and toner adheres to the carrier electrostatically. In the development process, toner is developed on photosensitive material, the carrier remains in the developing apparatus, and consequently, the same amount of toner as that developed is supplied from a stirring area.

The carrier charges the toner positively through friction. In this case, if the electrically charged amount of toner is small, overlap and spill will occur, due to toner scattering. On the other hand, if the amount of toner is large, insufficient image density occurs. Therefore, we need to stabilize the electrically charged toner to obtain a high-quality image.

However, because the charging force of the carrier decreases (durability) or the charged amount of carrier varies due to a change in environment such as temperature or humidity (environmental dependability), a problem with the charged amount of toner also occurs in the developer. To solve this, it is necessary to stabilize the charging characteristics of the carrier providing electrical charge to the toner.

2. Signal Factors and Charging Characteristics

Carriers whose charging characteristics are stable satisfy the following two requirements at the same time. We evaluated these two requirements.

1. *Generic function.* The time of stirring (mixing) with toner is proportional to an integral of the electrically charged amount of toner. As shown in Figure 2*a*, stable chargeability of carrier is considered to increase the charged amount quickly in accordance with the time of stirring with toner and to maintain a constant amount afterward. To comprehend its input/output relationship in a dynamic manner, we integrated the charged amount with respect to time, as shown in Figure 2*b*. As a result, an ideal function is proportionality between the time of mixing with toner and a time-based integral of the charged amount of

 Taguchi's Quality Engineering Handbook. Genichi Taguchi, Subir Chowdhury and Yuin Wu

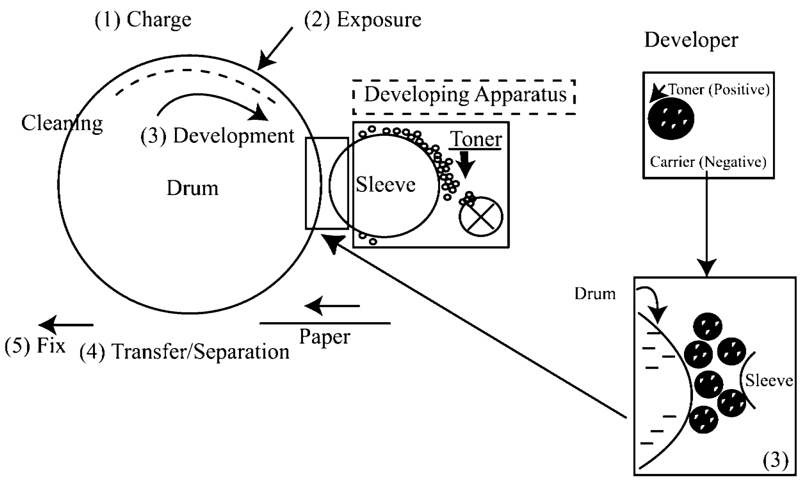

Figure 1
Electrophotography process

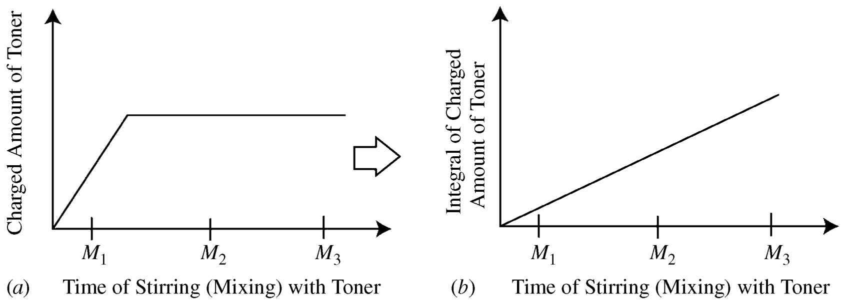

Figure 2
Generic function required for carrier

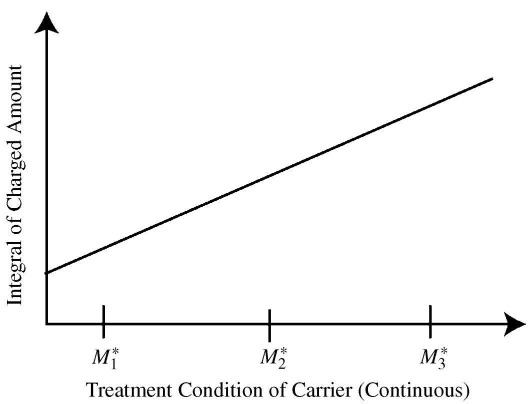

Figure 3
Adjusting the function required for the carrier

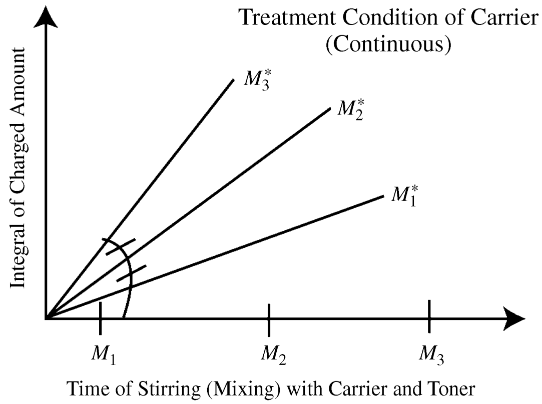

Figure 4
Function of the electrophotographic developer

Table 1
Output data of experiment 1 of an L_{18} orthogonal array

		1 (M_1)	10 (M_2)	20 (M_3)	Linear Equation
M_1^*	N_1	12.9	275.7	596.7	L_1: 14,703.9
	N_2	10.5	189.1	373.1	L_2: 9,363.6
M_2^*	N_1	17.2	341.7	718.2	L_3: 17,798.2
	N_2	11.9	226.5	458.5	L_4: 11,446.9
M_3^*	N_1	19.8	391.5	818	L_5: 20,294.8
	N_2	14.2	269.3	549.3	L_6: 13,693.2

toner. Its disturbed linearity means instability of the amount of charge, which is represented by its slope.

2. *Adjusting factors.* The treatment condition of the carrier is proportional to an integral of the electrically charged amount of toner. The carrier has the characteristic that its charging force varies in the early phase of imaging but becomes constant after a certain period. Thus, by treating the carrier beforehand, we adjusted an initial charging force to a constant charging force. By doing so, we reduced the fluctuation in the amount charged. Therefore, to obtain a desirable amount charged from the beginning, we should have a linear relationship between the treatment condition of the carrier and an integral of the amount charged (Figure 3). Its deviation from linearity indicates a fluctuation in the amount of toner charged in the initial stage of imaging.

As illustrated in Figure 4, the ideal function is the proportionality between the treatment condition of the carrier and an integral of the electrically charged amount of toner. In this case we evaluated it by setting the treatment condition (continuous) as an adjusting factor. To be brief, for this ideal function, (1) we evaluated proportionality between the treatment condition of the carrier and an integral of the electrically charged amount of toner by assessing an SN ratio that shows linearity, (2) and also evaluated a linear correlation between the treatment condition of the carrier and the charged amount of mixture of treated carrier and toner by assessing an SN* ratio that shows a linear characteristic of an equal interval.

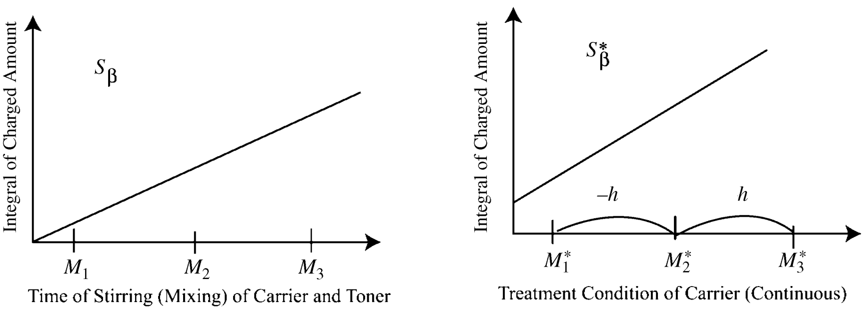

Figure 5
Developing function analysis

3. SN Ratio and Sensitivity

Our experiment was conducted in the following order: (1) by continuously changing the conditions, treat the carrier (M_1^*, M_2^*, M_3^*); (2) after treating the carrier in the toner, sample at a certain time interval (M_1, M_2, M_3); and (3) measure the sampled amount charged.

As noise factors, we selected the environment (the mixing environment with toner), and called low temperature and humidity (LL) N_1, and high temperature and humidity (HH) N_2.

Table 1 shows the output data of experiment 1 of an L_{18} orthogonal array. Additionally, we illustrate a basic process of simultaneous analysis of two signals in Figure 5.

Total variation:

$$S_T = 12.9^2 + \cdots + 549.3^2 = 2{,}699{,}075 \qquad (f = 18) \qquad (1)$$

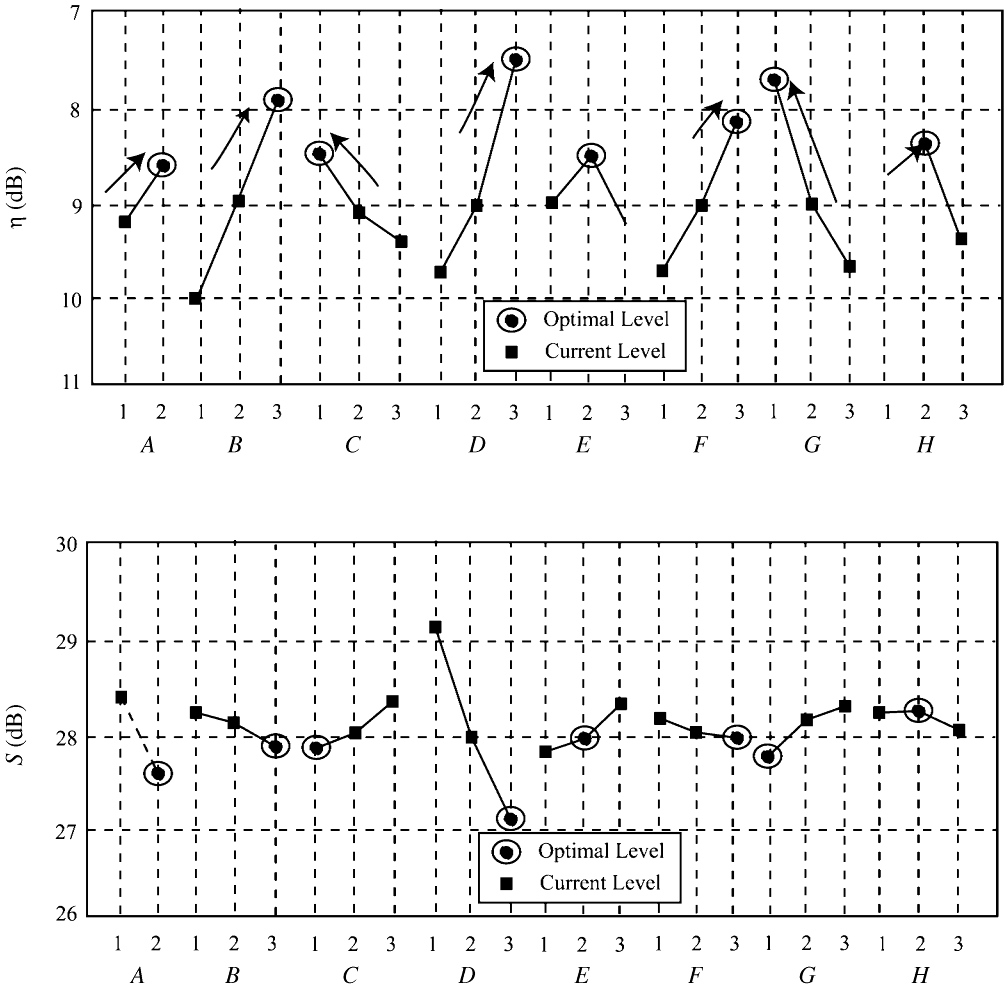

Figure 6
Response graphs of charging characteristic

Effective divider:

$$r = 1^2 + 10^2 + 20^2 = 501 \quad (2)$$

Linear equations:

$$L_1 = (1)(12.9) + (10)(275.7) + (20)(596.7)$$
$$= 14{,}703.9 \qquad L_2 = 9363.6 \qquad L_3 = 17{,}798.2$$
$$L_4 = 11{,}446.9 \qquad L_5 = 20{,}294.8 \qquad L_6 = 13{,}693.2 \quad (3)$$

Variation of proportional term:

$$S_\beta(\text{signal}) = \frac{(L_1 + L_2 + \cdots + L_6)^2}{(2)(3)(M_1^2 + M_2^2 + M_3^2)} = \frac{(14{,}703.9 + \cdots + 13{,}693.2)^2}{(2)(3)(1^2 + 10^2 + 20^2)} = 2{,}535{,}417 \quad (4)$$

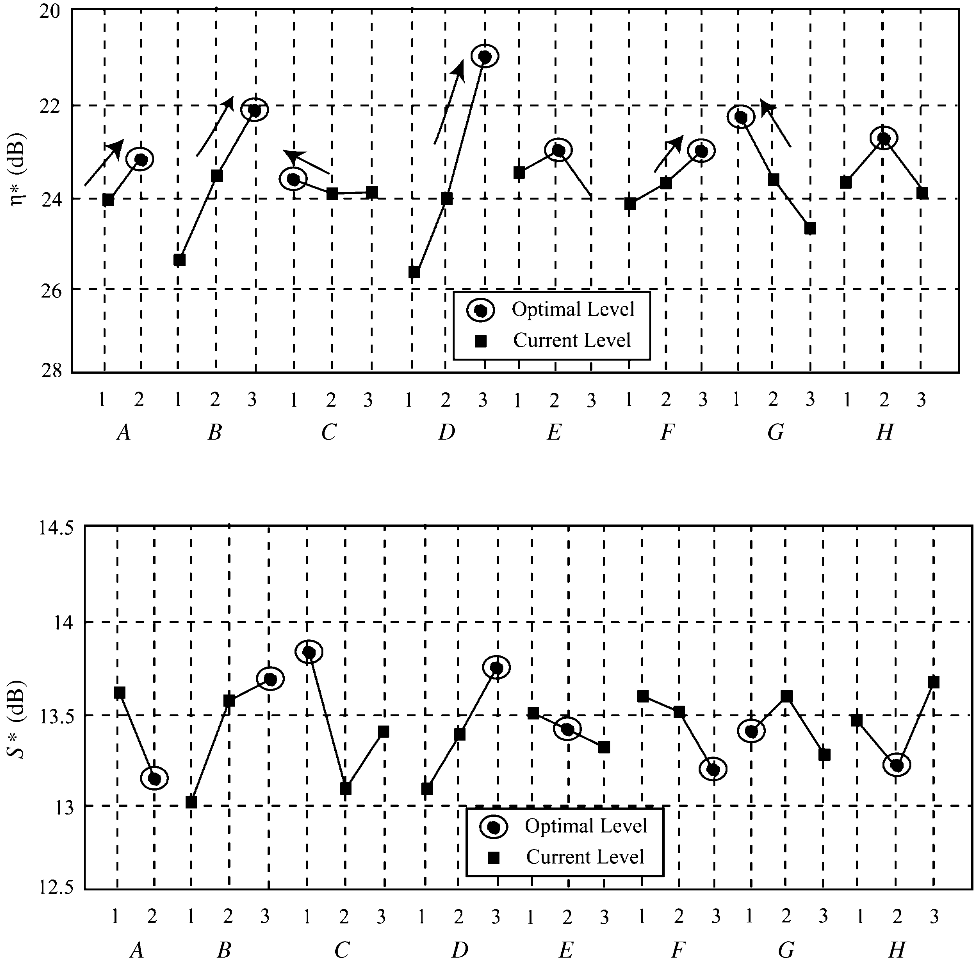

Figure 7
Response graphs of treatment condition

$S_{\beta*}$(adjusting)

$$= \frac{(-L_1 - L_2 + L_5 + L_6)^2}{(2)(2)(M_1^2 + M_2^2 + M_3^2)}$$

$$= \frac{(-14{,}703.9 - 9{,}363.2 + 20{,}294.8 + 13{,}693.2)^2}{(2)(2)(1^2 + 10^2 + 20^2)}$$

$$= 49{,}105 \quad (5)$$

Variation of proportional term difference:

$$S_{N\beta} = \frac{(L_1 + L_3 + L_5)^2 + (L_2 + L_4 + L_6)^2}{3r} - S_\beta$$

$$= 111{,}322 \quad (6)$$

Error variation:

$$S_e = S_T - S_\beta - S_{\beta*} - S_{N\beta} = 3231 \quad (7)$$

Error variance:

$$V_e = \frac{S_e}{15} = 215 \quad (8)$$

Total error variance:

$$V_N = \frac{S_{N\beta} + S_e}{16} = 7160 \quad (9)$$

SN ratio:

$$\eta = 10 \log \frac{[1/(2)(3r)](S_\beta - V_e)}{V_N} = -9.57 \text{ dB} \quad (10)$$

$$\eta^* = 10 \log \frac{[1/(2)(2r)](S_{\beta*} - V_e)}{V_N} = -24.96 \text{ dB} \quad (11)$$

Sensitivity:

$$S = 10 \log \frac{1}{(2)3r}(S_\beta - V_e) = 29.26 \text{ dB} \quad (12)$$

$$S^* = 10 \log \frac{1}{(2)2r}(S_{\beta*} - V_e) = 13.87 \text{ dB} \quad (13)$$

4. Response Graphs and Results of Confirmatory Experiment

Based on the results of the L_{18} experiment, we calculated process averages and created response graphs. Figure 6 shows charging characteristics, and Figure 7 shows treatment conditions. Comparing η and η* with respect to each control factor in Figure 6, we can see that all levels that have the highest SN ratio are identical. On the other hand, Figure 7 reveals that sensitivities S and S^* have a different characteristic.

As shown in Table 2, after choosing two factors regarding carrier formulation and six factors regarding manufacturing conditions as control factors, we conducted an L_{18} (2×3^7) experiment.

Table 3 summarizes the result of estimated and confirmed gains of η and S at current and optimal configurations. According to this table, we find that we obtain sufficient gain for the SN ratio and good reproducibility of the SN ratio and sensitivity. Figure 8 shows the result of M_3^*, which achieves the target sensitivity. At the optimal configuration, we can greatly reduce its variability related to environment compared to the current configuration.

To ascertain if the optimal configuration selected in our study is the most effective in the actual machine, by changing our evaluation environment (LL and HH) we assessed the current and optimal configurations. Since we had a difference of 14 μC/g at the current configuration and 6 μC/g at the optimal configuration, the optimal configuration diminished the difference related to environment by more than 50%.

Table 2
Control factors of developer

Control Factor		Level 1	2	3
A:	formulation	A_1	A_2	—
B:	manufacturing condition	B_1	B_2	B_3
C:	formulation	C_1	C_2	C_3
D:	manufacturing condition	D_1	D_2	D_3
E:	manufacturing condition	E_1	E_2	E_3
F:	manufacturing condition	F_1	F_2	F_3
G:	manufacturing condition	G_1	G_2	G_3
H:	manufacturing condition	H_1	H_2	H_3

Table 3
Estimation and confirmation of SN ratio and sensitivity of developer (dB)

	SN ratio		Sensitivity		SN ratio*		Sensitivity*	
Configuration	**Estimation**	**Confirmation**	**Estimation**	**Confirmation**	**Estimation**	**Confirmation**	**Estimation**	**Confirmation**
Optimal	−3.01	−0.30	26.08	27.68	−15.33	−14.90	13.78	13.08
Current	−9.33	−9.55	28.49	27.85	−24.36	−25.07	13.44	12.33
Gain	6.32	9.25	−2.41	−0.17	9.03	10.17	0.34	0.75

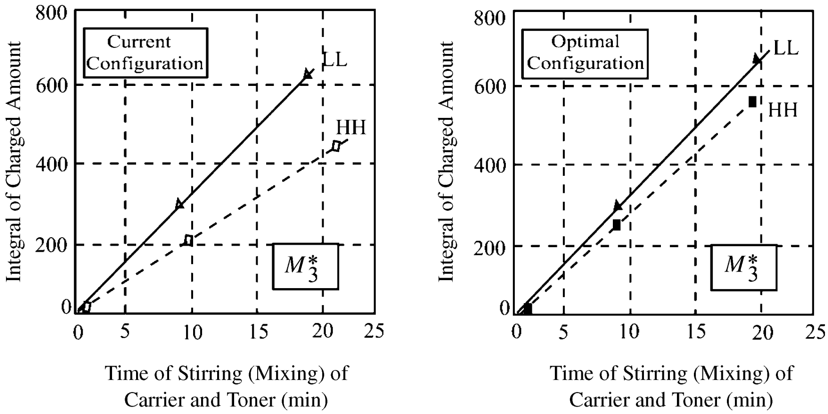

Figure 8
Results of confirmation experiment at current and optimal configurations

In addition, through durability (image stability) tests in the actual imaging, we confirmed that a new product reflecting the optimal configuration shows a more than fivefold durability compared to the current durability. Taking all the results into account, we proved that the optimal configuration obtained from the L_{18} experiment holds true for the actual machine.

5. Economic Calculation

Using the results of the experiment on actual imaging, we calculated the economic effect. While overlap and spill due to toner scattering occur when the amount charged falls below 10 μC/g, there is insufficient image density when it exceeds 40 μC/g. Thus, we can define functional limits as smaller than 10 μC/g and greater than 40 μC/g (range: 30 μC/g), respectively. The expected costs at functional limits were considered to be approximately 20,000 yen ($160), which includes both parts cost for replacement developer and service cost for repair personnel.

Thus, loss per photocopy machine can be calculated as follows:

$$L(\text{current}) = \frac{20{,}000 \text{ yen}}{(30/2)^2(14/2)^2} = 4360 \text{ yen (difference due to environment: 14 μC/g)} \quad (14)$$

$$L(\text{optimal}) = \frac{20{,}000 \text{ yen}}{(30/2)^2(6/2)^2} = 800 \text{ yen (difference due to environment: 6 μC/g)} \quad (15)$$

Based on this result, the difference in loss per product (ΔL) is

$$\Delta L = L(\text{optimal}) - L(\text{current}) = 3560 \text{ yen}$$

In other words, we can reduce loss per product by 3560 yen. Assuming that we sell 60,000 units annually, we can improve economic loss by 210,000 yen in a year.

Reference

Hiroyuki Kozuru, Yuji Marukawa, Kenji Yamane, and Tomoni Oshiba, 1999. Development of high quality and long life developer. *Quality Engineering*, Vol. 7, No. 2, pp. 60–66.

This case study is contributed by Hiroyuki Kozuru.