

## CASE 16

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# Optimization of Blow-off Charge Measurement Systems

**Abstract:** Our objective was to optimize the measurement functionality of a toner charge measurement device to achieve stable measurement for the charged amount of toner in the developing solvent. Although we calculated for one type of developing solvent, if we apply this method to other types, we will be able to accomplish many more economic benefits.

### 1. Introduction

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As a measurement device for the amount of toner charge, we selected blow-off charge measurement apparatus used widely because of its quick measurability and portability. Figure 1 depicts the magnified toner separator of the measurement system.

Our measurement procedure was as follows. Developing solvent consisting of toner and carrier was poured in a measurement cell that included a mesh at the bottom through which only the toner could pass. Then compressed air was blown into the cell, pushing the toner out while leaving the carrier, which has an equivalent but opposite-polarity charge to that of the separated toner. Finally, the amount of the charge is detected with an electrometer, and the polarity is read as opposite.

### 2. Generic Function

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The blow-off charge measurement separates the toner by stirring the developing solvent with blown air. However, this process might alter a state of charge in the developing solvent to be measured and disturb actual measured values.

We considered it ideal that blown-air energy be used to separate the toner with as little disturbance of the developing solvent as possible. In this ideal state, we hoped to find a true charge because there is no unnecessary, subsequent variation of charge

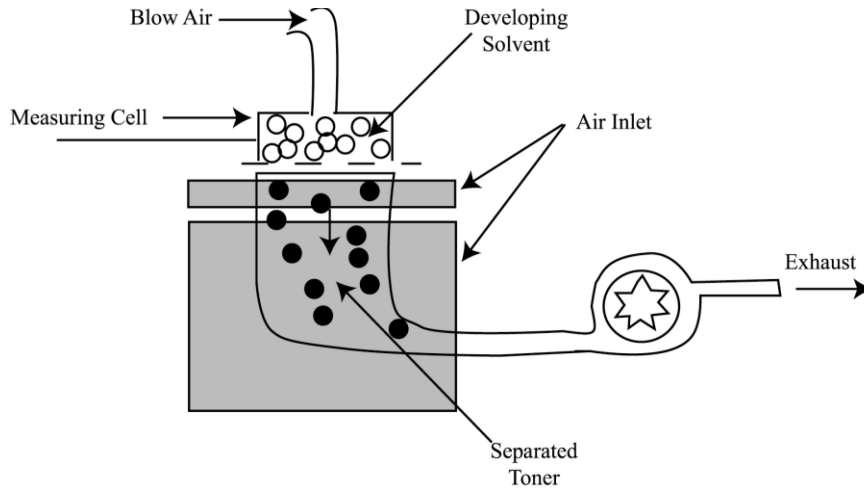
caused by measurement. In this case it was essential to evaluate a dynamic process in which toner is gradually being separated as the energy introduced increases. Since the amount of toner contained in the measured developing solvent is limited, even if we prolonged the blown-air time, the separation of toner would not increase beyond a certain level and would arrive at a state in which a new charge was not detected. In other words, because this toner separation process is analogous to a chemical reaction, if we selected a value corresponding to the reaction rate as output, we could utilize a chemical reaction equation in our research.

Therefore, we chose airflow time,  $M$ , as the input and mass separation rate,  $Y/M^*$ , as the output (Figure 2):

$$\begin{aligned} &\text{mass separation rate, } Y/M^* \\ &= \frac{\text{separated mass of toner, } Y}{\text{total mass of toner, } M^*} \end{aligned} \quad (1)$$

Now the total mass of toner,  $M^*$  could be measured by the mass density of toner in the developing solvent measured. On the other hand, the separated mass of toner,  $Y$ , is the total mass of toner separated from the beginning to the end of the blown air (Figure 3):

Additionally, we assumed that the mass separation rate,  $Y/M^*$ , is affected by the total amount of developing solvent measured. From our experience we assumed a relationship between blown-air time,  $M$ , and mass separation rate,  $Y/M^*$ .

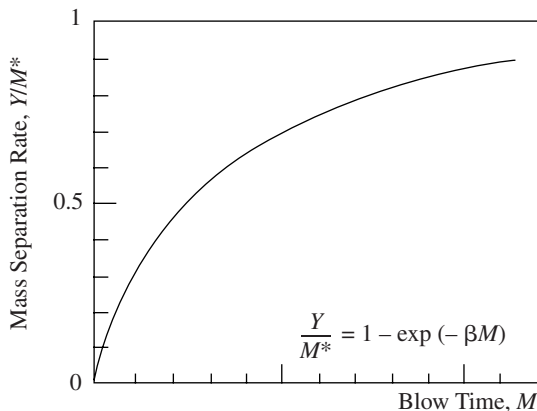


**Figure 1**  
Toner separator

When there is a fixed mass density of toner, since the total mass of toner,  $M^*$ , is proportional to the total amount of developing solvent, the relationship of the mass separation rate,  $Y/M^*$ , to the blown-air time,  $M$ , and total mass of toner,  $M^*$ , was presumed to be

$$Y/M^* = 1 - \exp(-\beta MM^*) \quad (2)$$

By taking a natural logarithm of both sides of equation (2), we obtained the following proportional equation through the origin:



**Figure 2**  
Blown-air time and mass separation rate

$$\ln[1 - (Y/M^*)] = -\beta MM^* \quad (3)$$

Now, substituting  $y = -\ln[1 - (y/M^*)]$ , we have

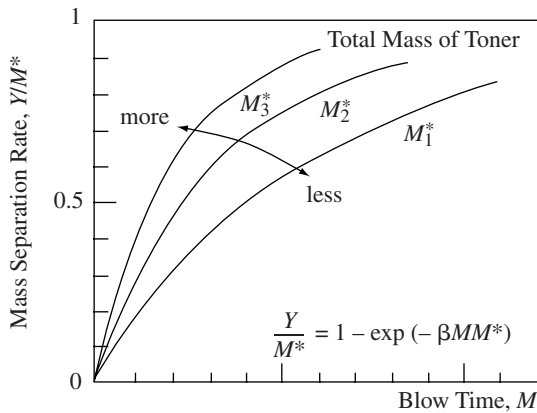
$$y = -\ln[1 - (Y/M^*)] \\ y = \beta MM^* \quad (4)$$

We selected blown-air time  $M$ , and total mass of toner,  $M^*$ , as signal factors. In this study we allocated the amount of developing solvent used to control factor  $B$ , which is discussed later. Because the total mass of toner  $M^*$  varies with the amount of developing solvent used and the mass density of toner,  $W$ , signal factor  $M^*$  and control factor  $B$  are not independent:

$$\text{total mass of toner, } M^* = (\text{amount of developing solvent used}) \times (\text{mass density of toner, } W) \quad (5)$$

Then we made signal factor  $M^*$  and control factor  $B$  independent by setting nominal 90 and 110% values of factor  $BW$  as levels of total mass of toner,  $M^*$ . Signal and level factors are shown in Table 1.

On the other hand, to optimize the measurement apparatus by focusing on its separation function, we dealt with the toner charge amount as a noise factor,  $N$ . With its true values of levels unknown, we prepared two levels close to the mini-



**Figure 3**  
Total mass of toner and mass separation rate

imum and maximum limits of the amount of charge favorable for development.

### 3. SN Ratio and Sensitivity

As an example, we chose experiment 9. The converted data are shown in Table 2. First, we calculated signal factor  $M^*$ . Setting mass density of toner  $W = 6$  wt % and using 898.0 mg as the amount of developing solvent, we computed the total mass of toner,  $M^*$ :

$$\begin{aligned} M_1^* &= \text{amount of developing solvent used} \times W \\ &= (898.0)(0.06) = 53.88 \end{aligned} \quad (6)$$

As a next step, we converted the mass of toner separated,  $Y_{11}$ , into the output,  $y_{11}$ . The mass of toner

separated was obtained from the experiment as  $Y_{11} = 2.0$  mg. We calculated the output,  $y_{11}$ , as follows:

$$\begin{aligned} y_{11} &= -\ln\left(1 - \frac{Y_{11}}{M_1^*}\right) \\ &= \ln\left(1 - \frac{2.0}{53.88}\right) = 0.0378 \end{aligned} \quad (7)$$

Since levels of signal factor  $M^*$  in Table 2 are representative values, each level of the signal factor depends on each value of output,  $y$ . The reason is that we cannot make each amount of developing solvent used completely identical. Needless to say, we computed SN ratios and sensitivities using each level of  $M^*$  measured.

Next, we give the calculation procedure for the SN ratio,  $\eta$ , and sensitivity,  $S$ .

Total variation:

$$\begin{aligned} S_T &= y_{11}^2 + y_{12}^2 + \dots + y_{33}^2 \\ &= 0.3117 \quad (f_T = 18) \end{aligned} \quad (8)$$

Effective divider:

$$r_i = (M_1 M_i^*)^2 + (M_2 M_i^*)^2 + (M_3 M_i^*)^2 \quad (9)$$

Linear equation:

$$L_i = (M_1 M_i^*) y_{1i} + (M_2 M_i^*) y_{2i} + (M_3 M_i^*) y_{3i} \quad (10)$$

Variation of proportional term:

$$S_\beta = \frac{(L_1 + L_2 + \dots + L_3)^2}{r_1 + r_2 + \dots + r_3} = 0.2703 \quad (f_\beta = 1) \quad (11)$$

Variation between proportional terms:

**Table 1**  
Signal and noise factors

Factor	Level		
	1	2	3
Signal factors			
$M$ : blown-air time	1	2	3
$M^*$ : total mass of toner	$BW - 10\%$	$BW$	$BW + 10\%$
Noise factor			
$N$ : toner charge amount	High	Low	

**Table 2**  
Logarithmized output data of experiment 9

Signal Factor, $M^*$	Noise Factor, $N$	Signal Factor, $M$			Effective Divider, $r$	Linear Equation, $L$
		$M_1$	$M_2$	$M_3$		
54	$N_1$	0.00378	0.1358	0.1343	40,713	38.38
	$N_2$	0.1027	0.1570	0.2086	28,641	47.14
60	$N_1$	0.0479	0.1045	0.1074	50,528	34.81
	$N_2$	0.1236	0.1340	0.2000	35,092	49.63
66	$N_1$	0.0370	0.1001	0.1197	60,582	39.24
	$N_2$	0.0897	0.1379	0.2106	42,151	54.72

$$S_{NB} = \frac{(L_1 + L_2 + L_3)^2}{r_1 + r_2 + r_3} + \frac{(L'_1 + L'_2 + L'_3)^2}{r'_1 + r'_2 + r'_3} - S_B \quad \eta = 10 \log \frac{[1/(r_1 + r_2 + \dots + r_3)](S_B - V_e)}{V_N}$$

$$= 0.0297 \quad (f_{NB} = 1) \quad (12) \quad = -33.7 \text{ dB} \quad (16)$$

Error variation:

$$S_e = S_T - S_B - S_{NB} = 0.0117 \quad (f_e = 16) \quad (13)$$

Error variance:

$$V_e = \frac{S_e}{f_e} = \frac{0.0117}{16} = 0.00073 \quad (14)$$

Combined error variance:

$$V_N = \frac{0.0297 + 0.0117}{1 + 16} = 0.00244 \quad (15)$$

SN ratio:

Sensitivity:

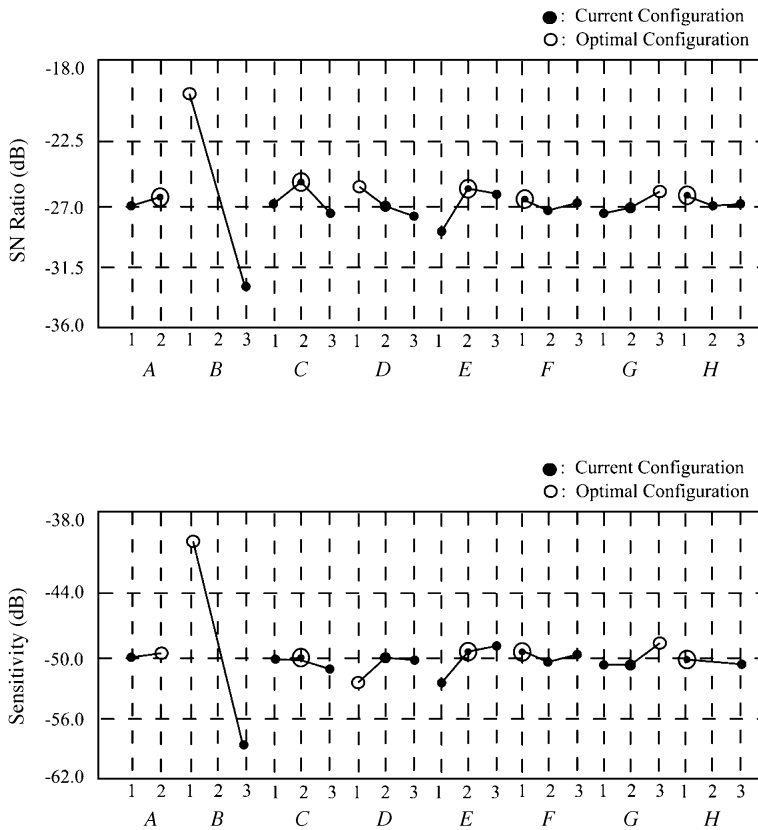
$$S = 10 \log \frac{1}{r_1 + r_2 + \dots + r'_3} (S_B - V_e) = -59.8 \text{ dB} \quad (17)$$

#### 4. Optimal Configuration and Confirmatory Experiment

As controls we selected two factors evenly from each of the factors developing solvent, pressure, airflow,

**Table 3**  
Control factors and levels

Control Factor	Level		
	1	2	3
A: Deviation of developing solvent	Yes	No	—
B: Amount of developing solvent	Small	Mid	Large
C: Primary pressure	Low	Mid	High
D: Secondary pressure	Low	Mid	High
E: Airflow amount	Low	Mid	Large
F: Airflow length	Short	Mid	Long
G: Air inlet shape	No. 1	No. 2	No. 3
H: Air inlet opening	Closed	$\frac{1}{3}$ closed	Open



**Figure 4**  
Response graphs

and apparatus design, and assigned all of them to an  $L_{18}$  orthogonal array (Table 3). Figure 4 shows factor effect plots for the SN ratio and sensitivity. According to these results, we selected the following configurations:

*Current configuration:*  $A_1B_3C_2D_2E_2F_1G_2H_1$

*Optimal configuration:*  $A_2B_1C_2D_1E_2F_1G_3H_1$

Table 4 shows the results of the confirmatory experiment. Consequently, we obtained high gains for

**Table 4**  
Confirmatory experiment (dB)

Configuration	SN Ratio		Sensitivity	
	Estimation	Confirmation	Estimation	Confirmation
Current	-29.8	-28.5	-55.8	-54.3
Optimal	-12.4	-17.4	-38.0	-41.0
Gain	+17.4	+11.1	+17.8	+13.3

both SN ratio and sensitivity. Figure 5 reveals that the optimal configuration enables us to improve the separation efficiency of the toner. However, we could not obtain sufficient reproducibility of gain. This was probably because of the interaction between control factors *C* and *D* (pressure) and control factor *E* (airflow amount).

To ascertain our achievement, we compared the optimal and current configurations using unit-mass charge amount  $q/m$ , expressed as

$$\frac{q}{m} = \frac{\text{charge amount detected, } q(\mu\text{C})}{\text{separated mass of toner (g)}} \quad (18)$$

By fixing the blown-air time, we measured the unit-mass charge amount,  $q/m$ , for two types of developing solvent used as noise. Calculating the nominal-the-best SN ratio of amount of charge obtained, we found that the optimal configuration achieves approximately +11 dB more gain than that of the current configuration. In short, we demonstrated that in optimizing charge amount measurement apparatus, it is appropriate to focus on its function to separate toner instead of measuring the amount of charge.

From the results obtained so far, we calculated the economic benefit related to inspection on an assumption regarding the gains confirmed by measuring the amount of charge. Setting the lower functional limit of the developing solvent to  $15 \mu\text{C/g}$  and the upper limit to  $30 \mu\text{C/g}$ , we have

$$\Delta_0 = 7.5 \mu\text{C/g} \quad (19)$$

Assuming that the developing solvent exceeded the functional limits as discarded, we regarded the cost per production lot as

$$A_0 = 1,000,000 \text{ yen } (\$8000) \quad (20)$$

Therefore, the loss coefficient,  $k$ , is as follows:

$$k = \frac{A_0}{\Delta_0^2} = 17,778 \text{ yen} \quad (21)$$

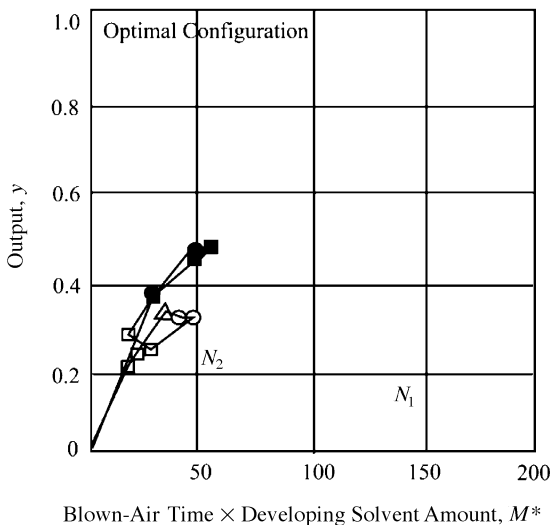
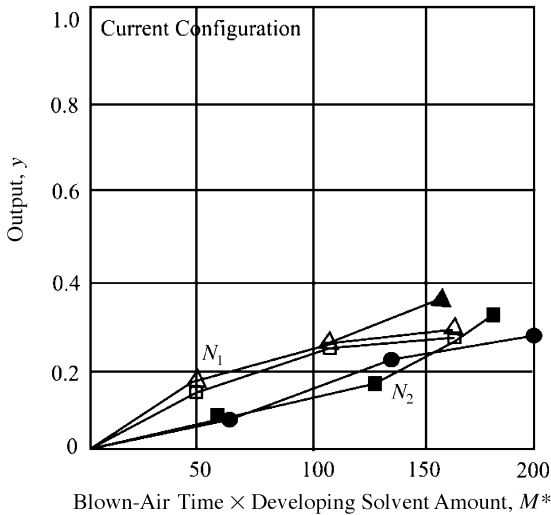
From the results of measurement of the amount of charge, we calculated the following values of  $\sigma$ :

$$\text{Current configuration: } \sigma_0^2 = \frac{S_0}{\eta_0} = 0.794 \quad (22)$$

$$\text{Optimal configuration: } \sigma^2 = \frac{S}{\eta} = 0.047 \quad (23)$$

Then the economic benefit per lot of developing solvent was computed as

$$\Delta L = (17,778)(0.794 - 0.047) = 13,280 \text{ yen} \quad (24)$$



**Figure 5**  
Confirmatory experiment (input/output)

Assuming a type of developing solvent whose production volume is 500 lots per year, we obtained

$$(13,280 \text{ yen})(500 \text{ lots}) = 6,640,000 \text{ yen/year} \quad (25)$$

an annual economic benefit of 6.64 million yen.

Although our calculations covered only one type of developing solvent, if we apply this method to other types, we will be able to accomplish many more economic benefits.

## Reference

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Kishio Tamura and Hiroyuki Takagiwa, 1999. Optimization of blow-off charge measurement system. *Quality Engineering*, Vol. 7, No. 2, pp. 45-52.

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*This case study is contributed by Kishio Tamura and Hiroyuki Takagiwa.*