Data Processing of Particle Size and Electric Charge of Electrophotographic Toner

Youichi Nakamura, Yoshinobu Moroboshi, Yutaka Terao,
Jun Tanabe and Taro Sekine
Nippon Institute of Technology, Minamisaitama, Saitama, Japan
Shuji Sasabe and Toyokazu Yokoyama
Hosokawa Micron Corporation, Hirakata, Osaka, Japan
Malay K. Mazumder
UALR, Little Rock, Arkansas

Abstract

Electric charge and particle size of electrophotographic toner particles for two-component developer can be measured as electrostatic charge and aerodynamic diameter by a laser-based instrument called the Electrical-Single Particle Aerodynamic Relaxation Time (E-SPART) analyzer. For characterization of toner in electrophotography, relationship between electric charge and particle size is also an important factor as well as their distributions. The relationship, however, has been scarcely examined. Based on the principle of the E-SPART method, new data processing software has been developed to show the dependence of electric charge on individual particle diameter in a stream of toner. It is also shown that the toner with the wider size range is more preferable for the experiments to investigate the correlation of the electric charge with the particle size. The size distribution of the toner samples for two-component developer is presented in the limited range from 2.0 to 25 μm.

Introduction

Characterization of electrophotographic toner is important in the research and development for electrophotographic field, because the toner particle plays a key role on the electrophotographic process. In the development process of electrophotography latent electrostatic images on the photoreceptor are properly transformed into toner images by electrostatic force. In order to characterize particle size or electric charge of toner many kinds of instrumentation have been investigated and used.[1-6] Most of them, however, are not able to obtain both informations of size and electric charge of toner particle. On the other hand, there are two methods which enable us to measure simultaneously size and electric charge of each particle of toner: one is an applied Millikan oil drop method[7] and the other is a method by a dual-beam frequency biased laser Doppler velocimeter with an acoustic wave perturbing a particle motion in the electric field. The former has some difficulty in measuring on a number of toner particles and the latter so called the Electrical Single Particle Aerodynamic Relaxation Time (E-SPART) method,[8] has also difficulty in obtaining the charge dependence on particle size of toner because of a lack of a desired data processing. For characterization of a number of toner particles, therefore, a modified E-SPART analyzer would be a preferable one in which sufficient data processing is conducted to visualize the relationship between electric charge and particle size on electrophotographic toner in addition to the customary data processing to provide electric charge distributions as well as size distributions. In this study we describe the scheme of data processing and deal with the statistical treatment of the experimental data on a few toner samples.

Principle of Operation

The E-SPART instrument is used to measure the aerodynamic diameter and the electric charge on each single particle in a stream of a number of toners guided downwards by air flow. There are the three basic parts of the instrument: (a) a dual-beam, frequency-biased laser Doppler velocimeter (LDV), (b) a relaxation cell and, (c) a data processing system. A schematic diagram of the E-SPART instrument is shown in Figure 1. The LDV measures particle velocity in the sensing volume which is located at the center of relaxation chamber.

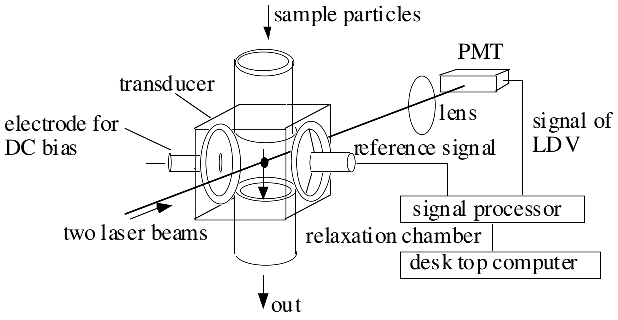

Figure 1. Schematic diagram of E-SPART instrument.

The dropping direction of the particle is vertically downwards through the sensing volume normal to the plane containing the two converging laser beams. Their movement with velocity of v in the relaxation cell is modified in the horizontal direction by acoustic excitation of a fixed frequency ω in air as shown in Figure 2 and the phase shift or log occurs. The phase log ϕ is expressed with Equation 1.

$$\phi = tan^{-1}\,\omega\tau \tag{1}$$

Here, τ is an aerodynamic relaxation time for the steady motion of the measured particle. When the effective diameter d of a particle is deduced from the supposed spherical body with particle density ρ, the relaxation time τ can be expressed as

$$\tau = (\rho d^2 C_C/18\eta) \tag{2}$$

Here, C_C is Cunningham slip correction factor and η is viscosity of air.

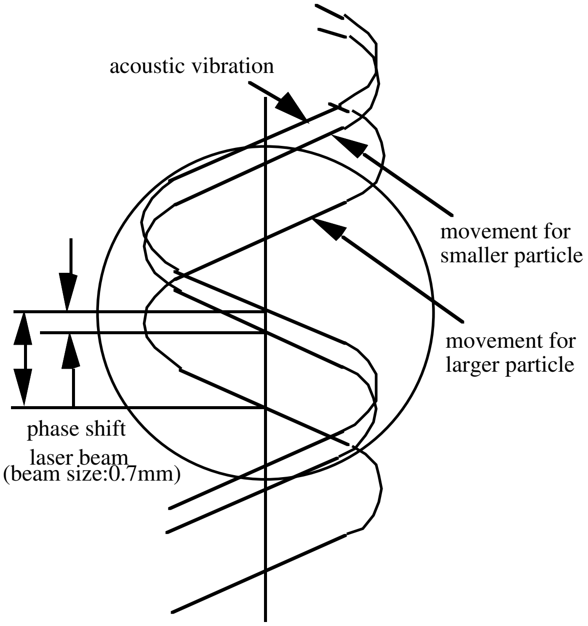

Figure 2. Principle of measurement of particle size.

From Equations 1 and 2, measurement of the phase log respect to the acoustic drive at a frequency ω can determine the relaxation time or the reduced diameter of particle. The limitation of $\phi < 65°$ for maintenance of accuracy in the present system with the acoustic frequency $\omega = 1$kHz leads to the allowable measuring range of diameter from 2.0 µm to 25 µm.

For measurement of particle charge of toner, a dc electric field is also superimposed upon the acoustic field. The movement of the charged particle is also modified in the horizontal direction at the same time, although the velocity shift depends on the polarity and the charge quantity q of the particle as shown in Figure 3. The modified component V of particle velocity by the dc electric field E can be written by Equation 3.

$$V = (q\,EC_C)/(3\pi\eta\,d) \tag{3}$$

Here, q is polarized charge quantity of the measured particle. From Equation 3 the electric charge for each particle of toner is also determined by the LDV velocimeter. A data processing system is deal with the set of the two kinds of data on the reduced diameter and on the charge of toner particle, and it consists of a signal processor and a personal computer aided with the extended and developed software. This new data processing software based on the principle of the E-SPART method enables us to deal with the statistical treatment of the experimental data for graphing and to present a group of the pair of the diameter value and the charge value for each particle in a number of toners more than one thousand.

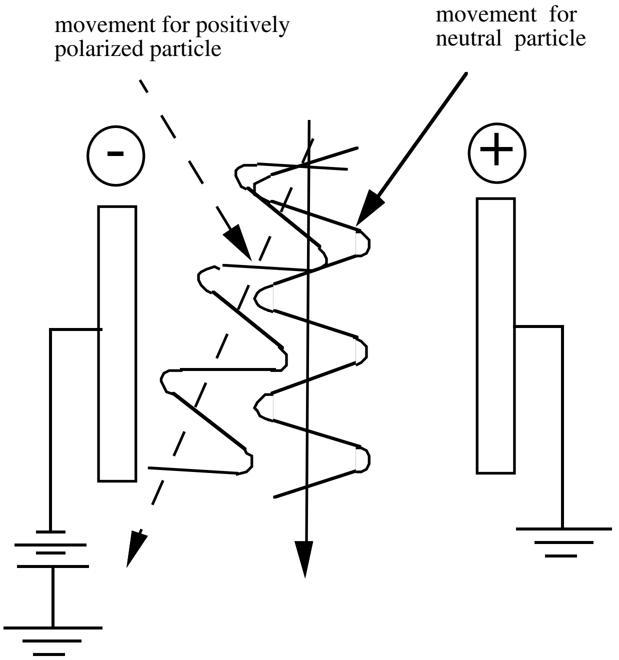

Figure 3. Principle of measurement of particle charge.

Experimental Procedure

Measurement of particle size and charge of toner was performed by the modified E-SPART analyzer. The acoustic frequency ω was adopted as 1 kHz. The supplier of toner sample was used for the two component developer type with a magnetic wheel. Calibration of particle diameter was carried out with the uniform Latex Microspheres of polystyrene of 3.09 µm (#5300A, Duke Scientific Co., Ltd) by a nebulizer. The measured samples to evaluate the new software were the two different species of toner by the same producer: Sample A was a "7µm" product and Sample B was a "14µm". The measuring range of the reduced diameter of toner from 2 to 25µm was divided into the 22 segments. The each segment had the 63 boxes of memory for the charge quantity of toner particle. The data of pair of diameter and electric charge on each particle was stored in the 22 × 63 memory boxes and was processed to obtain the informations of size d distribution, charge over size q/d distribution and charge q dependence on size d.

Results and Discussions

From the charge over size q/d distributions of Samples A and B, both of these showed to be mainly polarized negatively. In Figures 4 and 5 the charge dependences on the reduced diameter of toner for Samples A and B were shown respectively, where the experimental data was collected for

Table 1. Experimental Results for Toner Samples Obtained by E-SPART Analyzer.

Toner Samples		A	B
Aerodynanic	average value d_{av}	9.24	13.40
diameter (µm)	standard value σ_d	2.77	4.54
Charge of	average value q_{av}	2.22	11.30
particle (fC)	standard value σ_q	1.42	5.53
Correlation coefficient between diameter and charge		0.658	0.858

the count number of the measured particles from 1000 to 5000. The value of charge of toner was the absolute value of negative quantity as the average in each segment of diameter. From these figures the charge dependence on diameter showed a similar tendency in the cases for the count number more than 3000. There are some scattered points in the smaller region of particle size. The size distributions of Sample *A* showed a narrow peak near the region of average diameter as same as Sample *B*. This means that only a few particles were observed in the outer region of diameter apart from the average value.

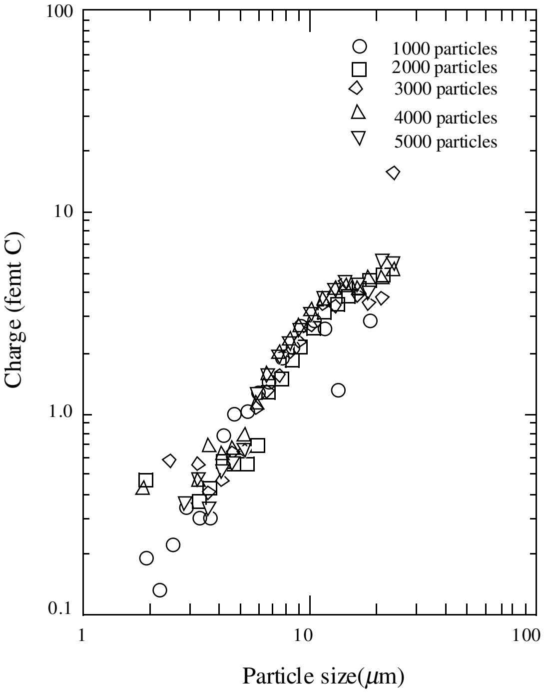

Figure 4. Charge dependence on the size of toner particles (Sample A).

In Table 1 the experimental results for the toner samples obtained by E-SPART analyzer were summarized for the count number of 3000. Toner of Sample *A* was polarized negatively for the particles of 89% of the count number whereas that of Sample *B* 95%. From Table 1, it was shown that toner of Sample *B* had the greater σ_d and σ_q than that of Sample *A*. Correlation coefficient between diameter and charge of Sample *B* was indicated to be 0.858 and to be also greater than that of Sample *A*.

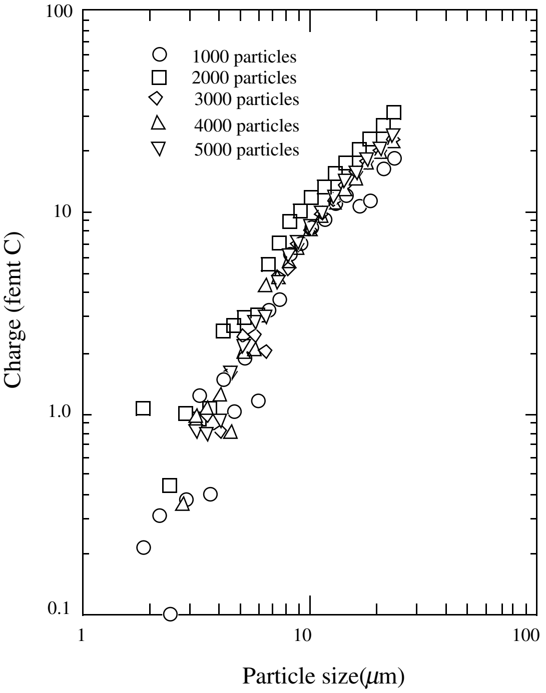

Figure 5. Charge dependence on the size of toner particles (Sample B).

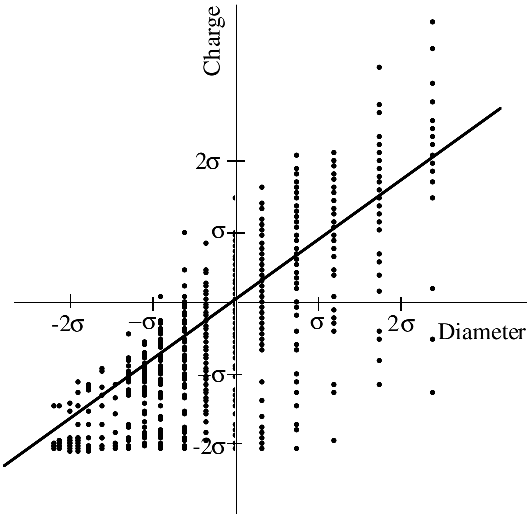

Figure 6. Distribution of normalized charge on normalized diameter (Sample B).

In Figure 6 the distribution of the normalized charge on the normalized diameter is shown for Sample *B*, where the unit in the diameter axis is σ_d of 4.54μm and the unit in the charge axis is σ_q of 5.53 fC and the origin indicates the coordinate of the average diameter d_{av} and the average charge q_{av}.

In this figure the charge dependence on diameter was able to be examined easily and clearly. The solid line in the figure was a regression line for the charge on the diameter in Sample *B*, and the correlation coefficient would correspond to a differential coefficient of the charge variable at the origin. The equation for the regression line is expressed as $(q - q_{av})/\sigma_q = 0.858(d - d_{av})/\sigma_d$. In this type of figure as Figure 6 it is applicable to display the charge dependence of diameter for the experimental data in the limited and narrow region of toner size.

On the other hand, in the log-log type figure as Figures 4 and 5, it is preferable to display the charge dependence of diameter for the data in the wider region of toner size. In order to evaluate the charge dependence of diameter on electrophotographic toner, it is necessary to examine it by the toner sample having a wide and broad distribution of size.

Summary

1. The extended software of data processing based on the principle of the E-SPART method was developed to deal with the charge dependence on diameter of electrophotographic toner particle.
2. Correlation coefficient between diameter and charge was obtained as the greater value for the sample which had a relatively wide distribution of diameter.
3. In the type of figure for the distribution of normalized charge on normalized diameter, it is applicable to show the charge dependence on diameter in the limited region of toner size.

References

1. D. K. Donald and P. K. Watson, *Photogr. Sci. Eng.* **14**, 1970, pp. 36.
2. R. B. Lewis, E. W. Connors and R. F. Koehler, *Electrophotography* **22**, 1983, pp.85.
3. R. H. Epping, *Proc. of 4th Int'l Congress on Advances in NIP*, 1988. pp.102.
4. J. Bares, *IEEE-IAS Ann. Meeting Conf. Record*, 1985, pp.1525.
5. B. D. Terris and K. J. Fowler, *J. Imaging Tech.* **17**, 1991, pp. 215.
6. N. Kutsuwada, S. Takayama, A. Nakano, S. Yamazaki and T. Suzuki, *J. Imaging Tech.* **11**, 1985, pp.287.
7. N. Kutsuwada and Y. Nakamura, *J. Imaging Tech.* **15**, 1985, pp.1.
8. M. K. Mazumder, R. E. Ware, T. Yokoyama, B. Rubin and D. Kamp, *IEEE-IAS Ann. Meeting Conf. Record*, 1987, pp.1606.