Measurement technique for electrostatic charge on single toner particle with MEMS-based actuated tweezers

Daichi Yamaguchi, Shuusuke Someno, Masaya Hamaguchi; Ricoh company, Ltd., 16-1 Shinei-cho, Tsuzuki-ku Yokohama 224-0035, Japan.

Abstract

A measurement technique for the charge on a single toner particle using nanotweezers (MEMS-based actuated tweezers) and an AFM cantilever has been developed. This unique system was designed to measure the image force on the cantilever induced by a charged toner particle gripped by nanotweezers. A method for calculating the toner charge from the image force has also been established by replacing the non-uniform charge distribution with an imaginary point charge. The proposed technique is validated with consistent results using the blow-off method and is promising for analyzing single isolated toner particles, e.g., fogging or transfer dust toner.

Introduction

The development process in electrophotography is based on electrostatic forces acting on charged toner particles in electric fields, and the amount of charge on the surface of the toner particles significantly affects the printed image quality of electrophotography. Therefore, it is important to precisely measure the amount of static electricity on the toner particles.

Several methods for measuring toner charge have been established. The blow-off technique, which is one of the most conventional methods in the field of electrophotography, measures the toner charge-to-mass ratio (q/m). [1] The electrical single-particle aerodynamic relaxation time analyzer (E-SPART) system has the advantage of measuring the aerodynamic size and electrostatic charge distribution of sub-micron particles in real time. [2] Although these measurement techniques are proven and practical, they cannot be used to measuring single isolated toner particles such as in fogging toner. During the last two decades, the atomic force microscopy (AFM) colloidal probe method has been widely used to investigate the interaction between a single particle and a substrate. The colloidal probe method is utilized to investigate the electrostatic state on the surface of micro-sized particles including toner as well as to measure the adhesion force of a single particle. [3–8] However, this methods requires gluing a particle to the AFM cantilever with epoxy resin, which prevents real-time measurement and may change the electrostatic state of the particle. Therefore, it is difficult to utilize the colloidal probe method for in situ measurement of the charge of toner particles on a photoconductor.

In this paper, we present a unique measurement technique for the charge on a single toner particle using nanotweezers (MEMS-based actuated tweezers) and an AFM cantilever. [9] The technique enables measurement of the charge on a single toner particle in a much shorter time compared with colloid probe method. After describing the details of the measurement setups, we will report the validation results and compare them with those of the conventional method.

Measurement principles

The proposed technique involves an image force measurement and the calculation of the charge from the measured image force. An overview of the image force measurement is shown in Figure 1. The nanotweezers pick up a single toner particle and position it close to the cantilever. The cantilever is mounted on a piezoelectric stage with a laser displacement meter that monitors the deflection of the cantilever. After the positioning procedure, the piezoelectric stage moves the cantilever towards the toner particle as shown in Figure 2. If the toner particle is charged, the cantilever is attracted to it due to the image force. The image force-distance curve is measured as the piezoelectric stage moves until the toner particle touches the cantilever.

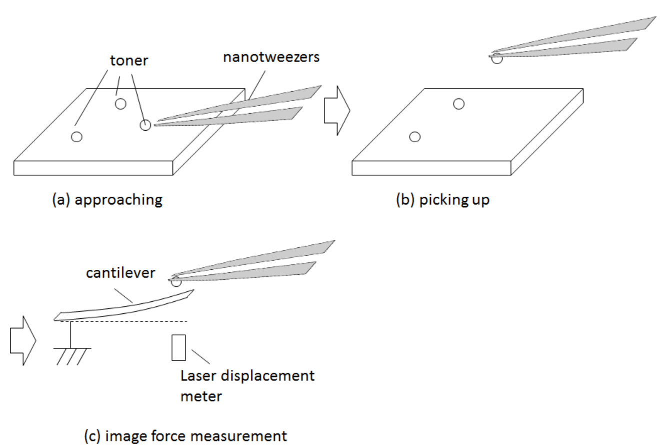

***Figure 1** Overview of toner particle pick up and toner image force measurement strategy using nanotweezers and an AFM cantilever*

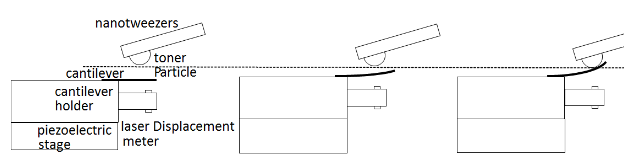

***Figure 2** Schematic diagram of image force measurement of single toner particle*

The measurement system can also identify the charge polarity of the particle. Specifically, the charge polarity can be determined by the relationship between the voltage polarity applied to the cantilever and the direction of the force acting on the cantilever, as illustrated in Figure 3. For instance, the polarity is determined to be positive when a positively biased cantilever experiences a repulsive force.

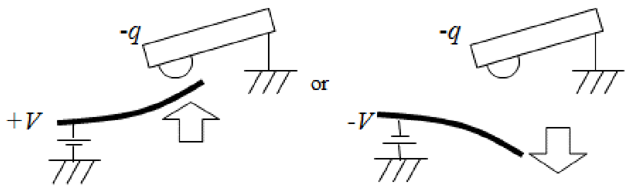

Figure 3 *Schematic diagram of charge polarity identification*

For the calculation of the amount of charge on the surface of the toner from the image force, we introduce a parameter for replacing the non-uniform charge distribution with a single point charge, which we name the imaginary center of charge, as shown in Figure 4. Several studies on the adhesion force indicate the non-uniformity of the charging distribution on the toner surface. They showed that the adhesion force of the toner is one order of magnitude larger than expected based on a spherically symmetric charge distribution model. Nishitani *et al.* reported that conversion of a non-uniform charge distribution into a point charge provides accurate fitting to the image force measured by AFM. [10] We applied the model proposed by Nishitani *et al.* to the calculation of the charge amount from the image force measured by our technique. Specifically, we determined the toner particle charge q and imaginary center of the charge r by least-squares fitting to equation (1), where d is the distance between the toner particle and the cantilever, k is the spring constant for the cantilever, and x is the deflection of the cantilever.

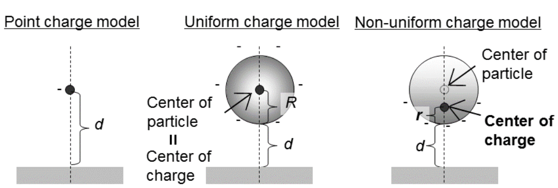

Figure 4 *Calculation model for toner charge*

$$\frac{1}{16\pi\varepsilon}\frac{q^2}{(d+r)^2} = kx \tag{1}$$

Experimental

We constructed the original measurement system shown in Figure 5. The system consists of nanotweezers with proximity sensing (Aoi Electronics Co., Ltd.), a force measurement unit with a cantilever, an optical microscope, and two stages (XY stage and Z stage). The positional relationship between the nanotweezers and the toner particle or cantilever was adjusted according to the optical microscope image. The XY stage moves the force measurement unit and the sample table horizontally. When picking up a toner particle, the sample table is positioned under the microscope. During image force measurement, the force measurement unit is moved under the microscope.

In the force measurement unit, a gold-coated cantilever (to which voltage can be applied) is mounted on a uniquely designed holder with a laser displacement meter. The piezoelectric stage moved the cantilever holder up and down for image force measurement.

Electrophotographic model toners with four different levels of charge were prepared to validate the measurement technique. The charge on the toners was adjusted by mixing them with carriers produced under different coating conditions. A toner mixed without carrier particles, which was estimated to be substantially uncharged, was also prepared. The toner particles had an average diameter of 5 μm, and they were deposited on a Si substrate for evaluation.

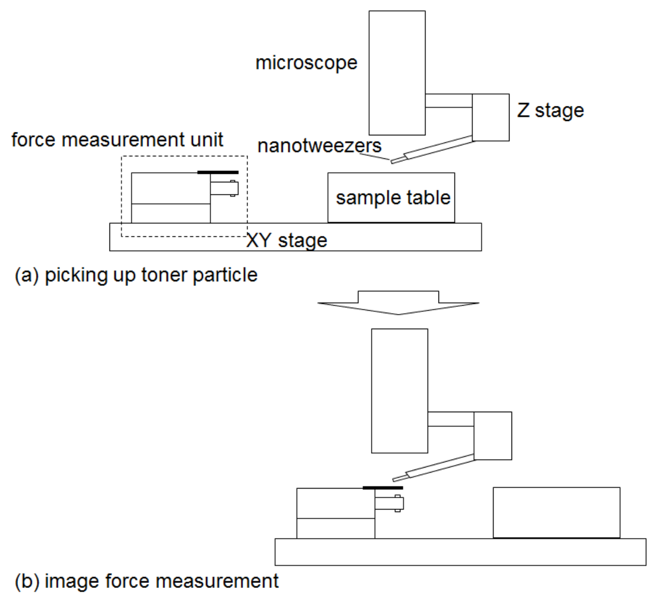

Figure 5 *Experimental apparatus for image force measurement for single toner particle*

Validation of measurement technique

Figure 6 shows a typical force-distance curve obtained by the proposed measurement system. A single particle chosen at random from the toner powder with a charge-mass ratio of -33.2 uC/g was evaluated. A force-distance curve obtained without gripping the particle with nanotweezers is also shown in Figure 6 as a reference. A long-range attractive force is observed for the case of gripping the toner, whereas no significant long-range force is detected for the case where nothing is gripped. For a distance of several micrometers between the particle and cantilever, the effects of the meniscus force and the van der Waals force can be neglected. We conclude that the obtained force curve shows only the image force due to the electrostatic charge generated on the toner particle.

Fitting results are also shown in Figure 6 for a charge of q=0.82 fC and an imaginary center of charge at r=1.37 μm. The measured image force is fitted precisely based on the model with an imaginary center of charge.

Figure 7 shows a typical result for charge polarity identification. In the same way as Figure 6, a single charged particle selected from the toner powder with a charge-mass ratio of -33.2 uC/g was evaluated. In Figure 7, the cantilever attracts the toner when a positive bias is applied to the cantilever, but repels the toner when a negative bias is applied. This result proves that the toner particle has a negative charge.

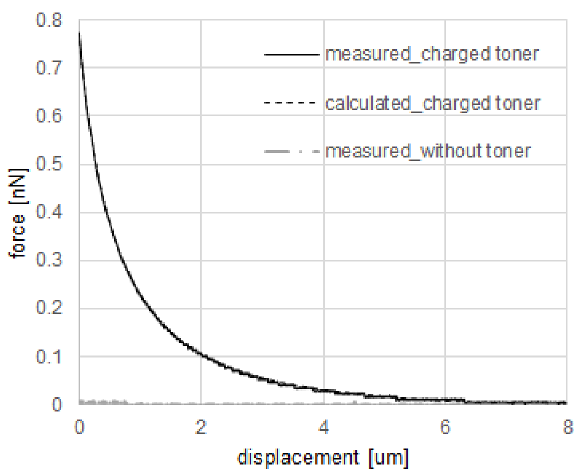

Figure 6 *Typical force-distance curve for charged toner*

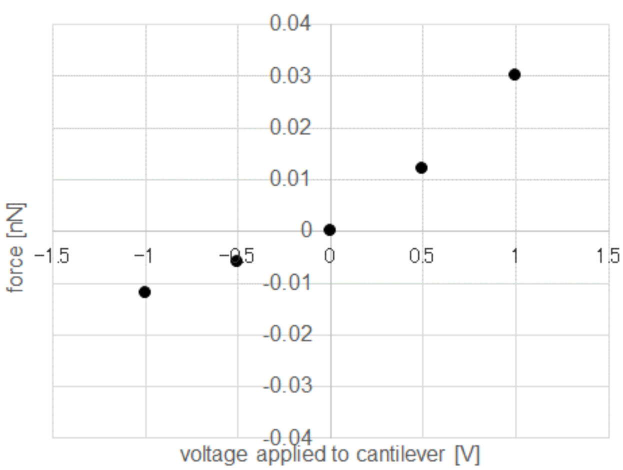

Figure 7 *Typical result for charge polarity identification*

Figure 8 shows image force-distance curves for toner particles with different levels of charge. Each graph includes the results for 7 particles selected randomly from each sample. Figure 8 demonstrates that the image force measured by the proposed method increases with increasing charge-mass ratio measured by the blow-off method. This result indicates that gripping the toner particle with nanotweezers has little effect on the charge state of the particle.

Figure 9 shows the toner charge calculated from the image forces shown in Figure 8. It can be seen that the calculated charge increase with increasing charge-mass ratio measured by the blow-off method. Thus, the toner charge was successfully calculated.

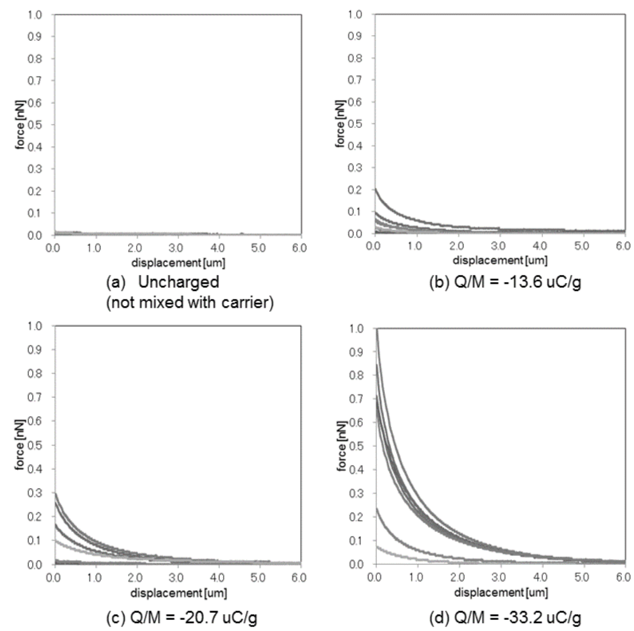

Figure 8 *Image force-distance curve for charged toner*

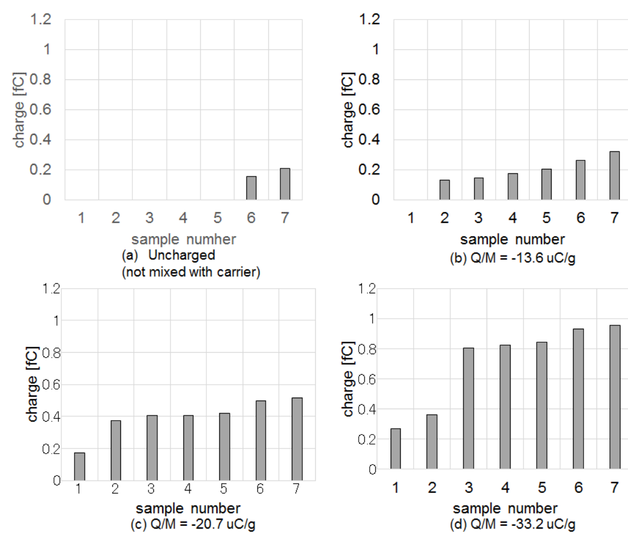

Figure 9 *Comparison between proposed technique and blow-off method*

A comparison between the average values for Figures 9(b), 9(c), and 9(d), and the blow-off method results is shown in Figure 10. It can be seen that there is a linear relation between the results obtained by the proposed technique and the blow-off method, which confirms the validity of the proposed technique.

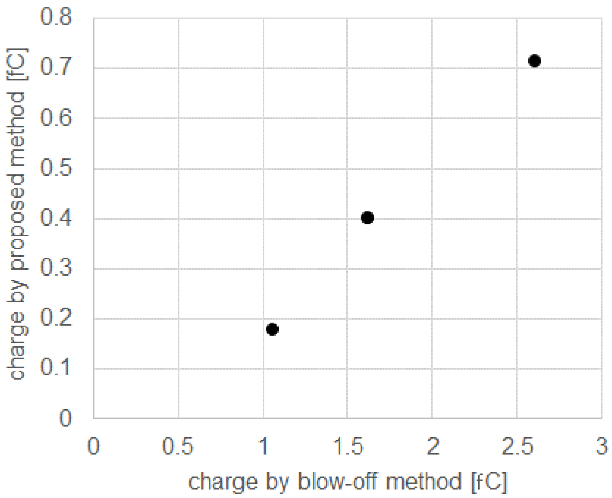

Figure 10 *Comparison of single toner charge obtained using proposed and conventional methods*

Conclusions

In this paper, we proposed a novel measurement technique for determining the charge on a single toner particle. A unique system for measuring the image force induced in the cantilever was designed. A method of calculating the charge was also developed using a non-uniform charge distribution model instead of a point charge model. The measurement technique was validated by comparing it with the blow-off method. We conclude that the proposed technique will allow the analysis of single isolated toner particles, e.g., fogging or transfer dust toner.

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Author Biography

Daichi Yamaguchi received a Master of Engineering Degree in Applied Physics from Waseda University in 2002 and joined The Ricoh Company, Ltd. He has been working on analysis and modelling of physical phenomena related to electrophotography.