A New Method for Measuring the Image-force to Gravity Force Ratio of a Toner Particle

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Abstract

Forces which act on a positively charged toner particle between parallel horizontal electrodes are the image-force, the gravity force and the Coulomb force. From the movement of toner particles under these condition, the image-force (f_0) to the gravity force (mg) ratio (f_0/mg) is calculated by the following equation:

$$f_0/mg = (V_1 + V_2)/(V_1 - V_2)$$

where V_1 is the voltage difference between parallel electrodes when the charged toner particle is about to leave the lower electrode toward the upper one, V_2 is the voltage difference when the same particle is about to leave the upper electrode toward the lower one, and g is the acceleration due to gravity. By using this relation, the value of f_0/mg can be calculated easily.

Introduction

We have already reported a technique for measuring q/m.[1] In this paper, we will present a technique for measuring the value of f_0/mg for both spherical and non-spherical toner particles and examine experimentally how much the image force has an effect on motion of the toner particle.

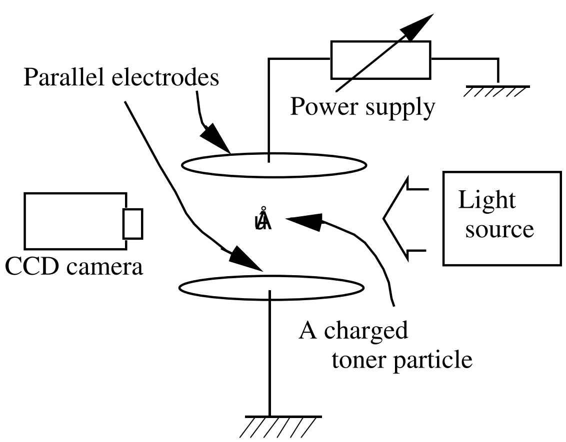

Figure 1. Schematic configuration for measuring f_0/mg.

Measurement Procedure

The schematic diagram of the experimental setup is shown in Figure 1. A charged toner particle is put on the lower of two parallel horizontal electrodes. In the gap space between parallel electrodes, we might assume the following three forces acting on this toner particle: (1), (2), and (3).

(1) The image force acting on a toner particle adhered to the surface of this electrode is given as:

$$f_0 = q^2/16\pi\varepsilon_0 r^2 \quad (1)$$

where r and ε_0 are the radius of the toner particle, and the permittivity of the gap space, respectively.

(2) The Coulomb force acting on the toner particle due to the electric field is given as:

$$f_1 = q(V/d) \quad (2)$$

where q, V, and d are the charge of the toner particle, the voltage applied across the parallel electrodes, and the air gap distance between the electrodes, respectively.

(3) The gravity force acting on the toner particle is given as

$$f_2 = mg \quad (3)$$

where m and g are mass of the toner particle and the acceleration of gravity, respectively.

In Figure 2(a), a sufficient condition that the charged toner particle should leave electrode **A** toward electrode **B** is:

$$qV_1/d \geq mg + f_0 \quad (4)$$

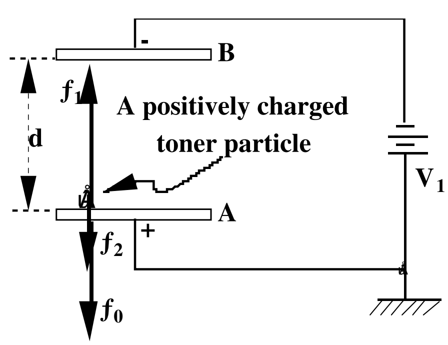

Figure 2(a). A charged toner particle adhered on the surface of electrode A.

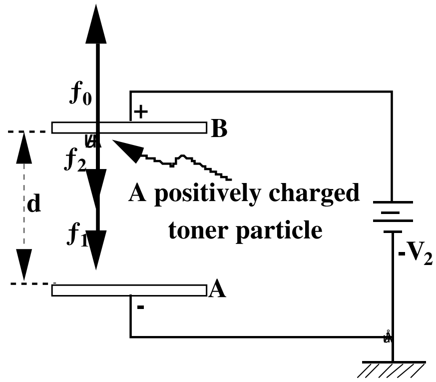

Figure 2(b). A charged toner particle adhered on the surface of electrode B.

In Figure 2(b), a sufficient condition that the charged toner particle should leave electrode **B** toward electrode **A** is:

$$-qV_2/d \geq mg - f_0 \tag{5}$$

From Equations (3) and (4), charge-to-mass ratio q/m is calculated by the following equation:

$$q/m + 2gd/(V_1 - V_2) \tag{6}$$

and the value of the image force is calculated by the following equation:

$$f_0 + q(V_1 + V_2)/2d \tag{7}$$

The ratio of image force to gravity force f_0/mg is calculated by the following equation:

$$f_0/mg = (V_1 + V_2)/V_1 - V_2) \tag{8}$$

From Equation (1), $q = 4\pi r^2 q_0$, and $m = (4/3)\pi\, r^3\sigma$, f_0/mg can be calculated as follows:

$$f_0/mg = 3q_0^2/4\varepsilon_0 r\sigma g \tag{9}$$

where σ and q_0 are the density of the toner particle and the charge density per unit surface area, respectively.

The relationship between r and f_0/mg using a parameter q_0 is calculated as shown in Figure 3.

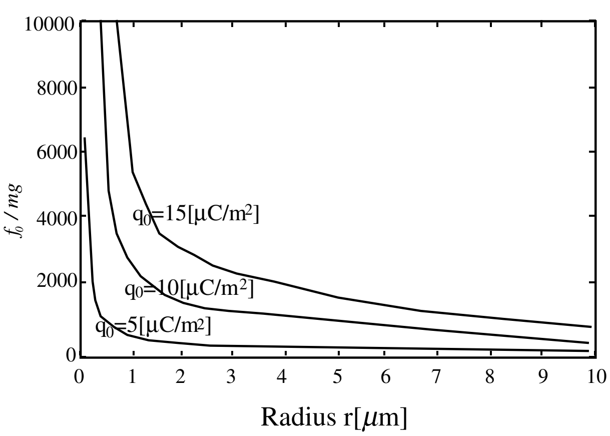

Figure 3. Relationship between r and f_0/mg as a parameter of q_0.

Experiment

Consider the measurement for the value of f_0/mg using Equation (8).

(1) Case of a spherical toner particle.
A micrograph of the spherical toner particles which are used for this experiment is shown in Figure 4.

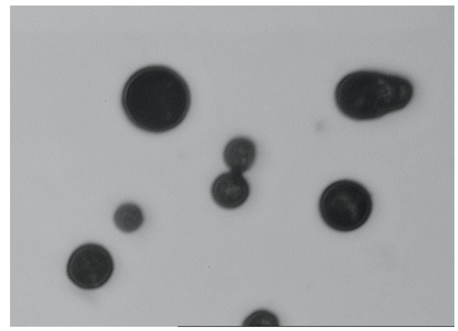

Figure 4. Micorgraph of the spherical toner particles.

The circular rate and the average radius for the sample of toner particles are shown in Table 1.

Table 1.
Geometrical characteristics of the spherical toner particles.

	average radius [μm]	circular rate
average	5.51	0.87
standard deviation	1.01	1.05
maximum	8.94	0.93
minimum	2.74	0.79

It is evident from this table that the toner particles which are used here are almost spherical. Table 2 shows the experimental results of f_0/mg. In this experiment, minimum and maximum voltages (V_1 and V_2) are about 50 and 260 [V], respectively. In this case, the maximum value of f_0/mg is about 647. The frequency distribution of V_1-V_2 values for the spherical toner particles is shown in Figure 5.

Table 2
Experimental result of f_0/mg values for the spherical toner particles.

	average	standard deviation	maximum	minimum
Voltage V_1 [V]	147.17	60.44	259.30	51.40
Voltage V_2 [V]	146.40	60.42	258.50	50.50
f_0/mg	382.25	183.39	647.25	113.22
q/m [μC/g]	3.83	0.93	3.86	3.27

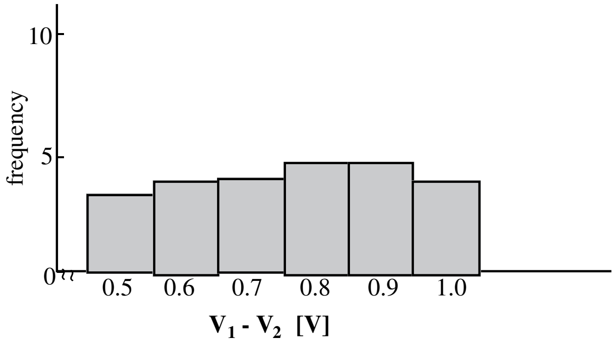

Figure 5. Frequency distribution V_1-V_2 values for the spherical toner particles.

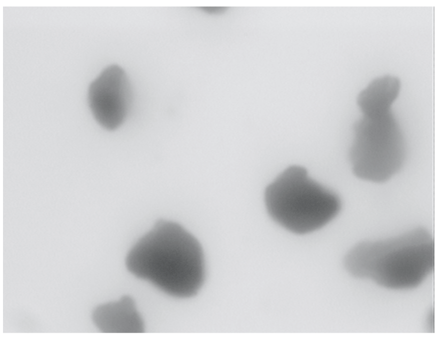

Figure 6. Image of the non-spherical toner particles.

Table 3.
Geometrical view for the non-spherical toner particles.

	average radius [µm]	circular rate
average	5.10	0.76
standard deviation	1.30	0.05
maximum	9.82	0.87
minimum	1.86	0.58

(2) Case of a non-spherical toner particle.
A micrograph of non-spherical toner particles is shown in Figure 6. The sphericity and the average radius for the sample of toner particles are also shown in Table 3.

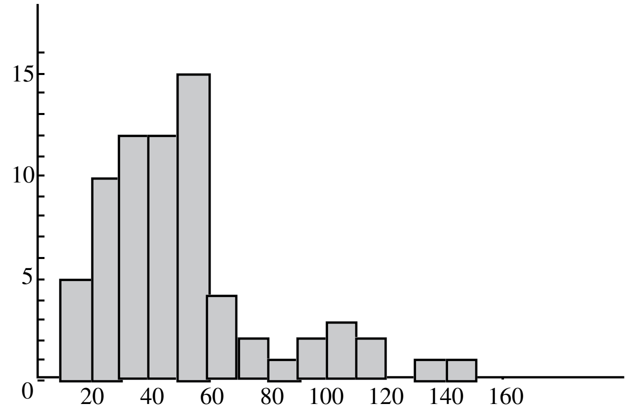

Figure 7. Frequency distribution V_1-V_2 values for the non-spherical toner particles.

For the toner particles shown in Figure 6, the distribution of charge on the surface of the particles is probably nonuniform, due to the non-sphericity of the surface of toner particles.

Figure 7 shows the experimental result of the frequency distribution of the toner particles as a function of V_1-V_2. From this figure, the value of V_1 -V_2 in the case of non-spherical toners is higher than that of spherical ones. Consequently, this technique can't be used for the measurement of f_0/mg in the case of non-spherical toners.

Conclusion

We have proposed a technique for measuring the ratio of image force to gravity force acting on toner particles using the polarity of the voltage applied across two horizontal electrodes. Using this technique, we can easily obtain the value of V_1 - V_2. This technique is useful for spherical toner particles.

References

1. Y. Yamamoto, K. Taniguchi, H. Yamamoto, and K. Matsubara, “A New Technique for Measuring the Charge-to-Mass Ratio q/m of a Toner Particle.” *IS&T’s Tenth International Congress on Advances in Non-Impact Printing Technologies* (1994), pp. 165-167; (see page 186, this publication).