A New Technique for Measuring the Distribution of Charge-to-Mass Ratio for Toner Particles with On-Line Use

Keiji Taniguchi, Hiroaki Yamamoto, Yutaka Nakano, Takanori Sakai, Syuichi Morikuni, and Sadakazu Watanabe

Department of Information Science, Faculty of Engineering, Fukui University, Fukui, Japan

Yoichi Yamamoto▲

LCD System Devices Development Center, SHARP Co., Nara, Japan

In this paper, we present a technique for measuring the value of charge-to-mass ratio in toners using a newly developed apparatus in which charged toner particles are transported above a periodic array of conductors driven by four-phase rectangular pulses. At the end of the flow path of toner particles in the transport system, parallel electrodes are set up for sensing charge-to-mass ratio. The sensed input signal is amplified by differential amplifier and is converted to digital values. By analyzing the sensed signal, the value of the ratio for the charged toner particles can be calculated. This technique can measure easily the mean value and its distribution under coditions of on-line use. We find that the distribution shows a good correspondence with the result of the E-Spart method near the peak range.

Journal of Imaging Science and Technology 47: 224–228 (2003)

Introduction

The charge (q) to the mass (m) ratio q/m of toner particles plays an important role for developing the quality of printers or copy machine systems. For this reason, the small size of apparatus for measuring q/m is desired for on-line use. However, so far, various kinds of apparatus have been developed only for off-line use.[1] As a practical method for measuring q/m, the Laser Doppler method has been widely used.[2] This is also known as "E-SPART Method", and is very convenient for off-line measurement of q/m.

As already reported in the literature,[3–5] we have developed a new method for measuring q/m off-line. In this method, a transparent electrode is used for observing the movement of a toner particle. The operation of this method is as follows:

Initially, a toner particle that is located on the surface of the lower electrode, is lifted toward the upper one by the electric field based upon the applied voltage V_1 across the parallel electrodes. The toner particle which adheres on the inner surface of the upper electrode is returned to the lower one by the reverse electric field, with the negative applied voltage $-V_2$. From these operations for the toner particle, the value of q/m is calculated from the applied voltage, the gap distance between the parallel electrodes and the acceleration due to gravity. However, it is not suitable for on-line measurement because it is necessary to observe the movement of the toner particle using an optical microscope.

Another new method we have also developed, is the vibration method.[6–9] The operation of this method is as follows:

At first, toner particles are placed on the lower side of a pair of parallel electrodes constructed by a piezoelectric element. Next, a rectangular voltage pulse is applied to drive the piezoelectric electrode. Consequently, a sinusoidal damped oscillation of the lower electrode occurs. Thereby, the toner particles are vertically thrown up toward the center of the gap between the parallel electrodes. In this situation, two image forces that act on the toner particles from upper and lower electrodes are canceled at the mid-point.

As a result, we obtain the equation

$$\sum (q/m) = {gd}/{V} ,$$

where V, d and g are the applied voltage between parallel electrodes, the gap between parallel electrodes, and the acceleration of gravity, respectively: the derivation of this equation is shown below. Analyzing the waveform obtained from the detecting amplifier, we can estimate the value of $\Sigma(q/m)$ for charged toner particles.

As a new method,[10] we present here the technique for measuring $\Sigma(q/m)$ at the end of the flow path in a toner transport system driven by a traveling wave.[11,12]

Theory

Figure 1 illustrates the relationship between toner particles above a sheet of printed periodic array conduc-

Original manuscript received May 22, 2001

▲ IS&T Member

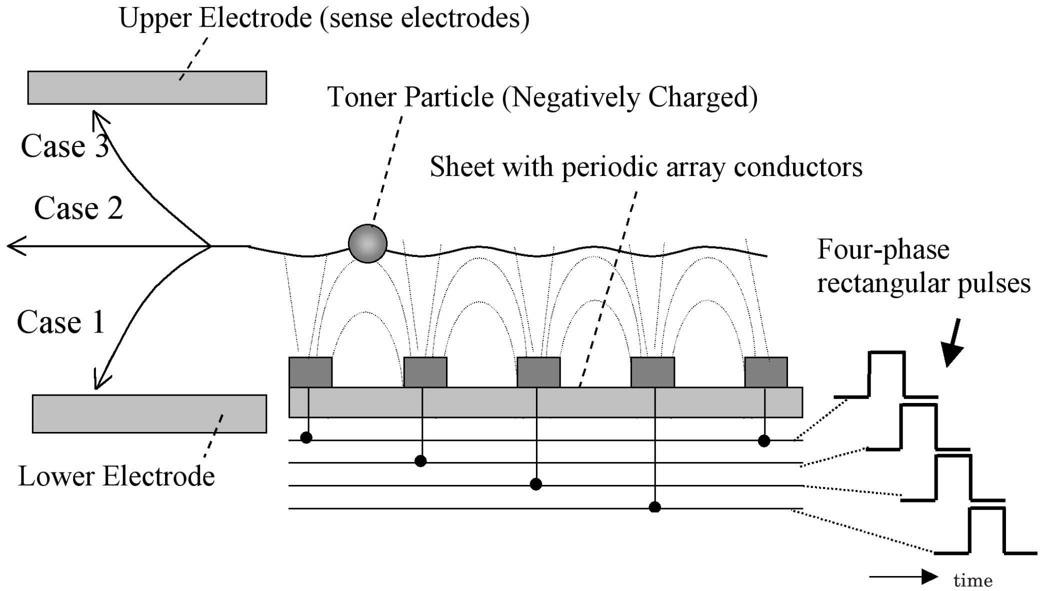


Figure 1. Movement of a toner particle on the periodic array conductors.

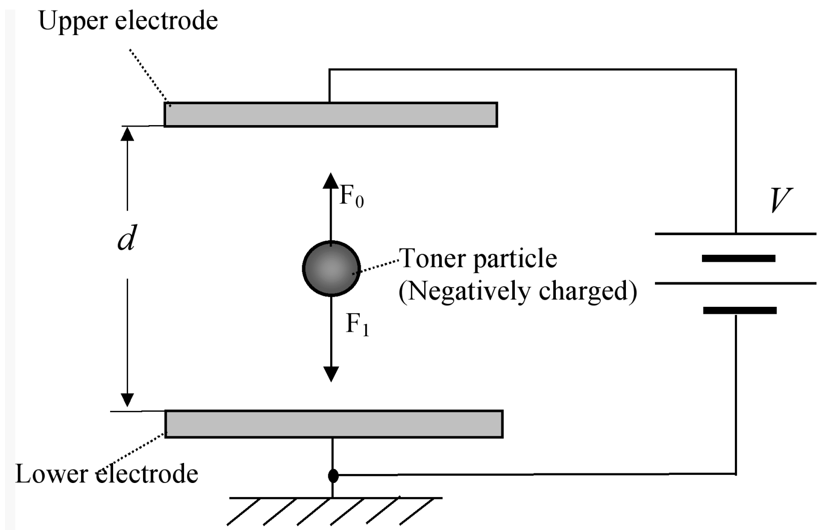


Figure 2. Movement of a toner particle between parallel electrodes.

tors driven by the four-phase rectangular pulses and parallel electrodes for sensing charged toner particles.

Let us consider the situation that a toner particle is moved toward the parallel (sensing) electrodes placed at the end of left side of the transportation system. In the air gap between parallel electrodes shown in Fig. 2, the following two forces act on the toner particle. The image force is neglected here.

(1) The Coulomb Force, F_0, Due to the Electric Field Caused by the Power Source is Given as Follows:

$$F_0 = q\ (V/d). \tag{1}$$

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

(2) The Gravity Force F_1 is Given as Follows:

$$F_1 = m\ g. \tag{2}$$

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

From the relationships between F_0 and F_1, there are three major cases, as shown in Fig. 2.

Case 1: $$F_0 < F_1\ . \tag{3}$$

In this case, the charged toner particle moves from the air gap between parallel electrodes toward the lower electrode.

Case 2: $$F_0 = F_1\ . \tag{4}$$

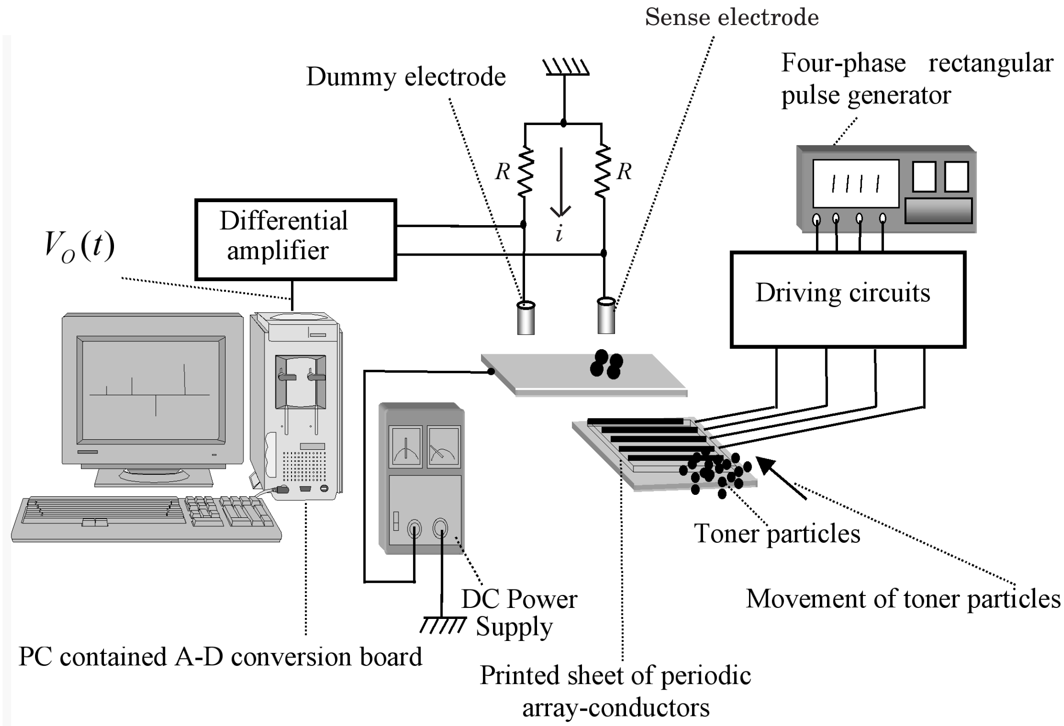
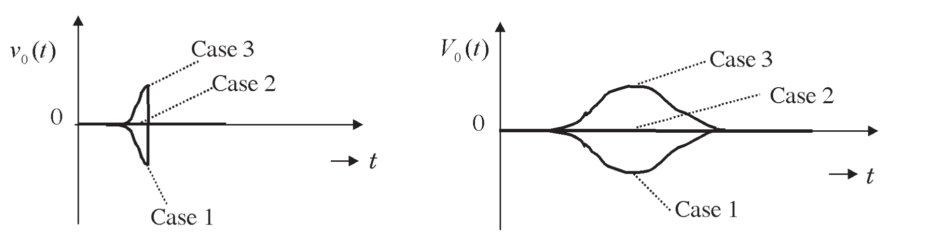


Figure 3. Schematic diagram of the experimental system.



(a) Sensed signal due to a toner particle (b) Sensed signal due to mass of toner particles

Figure 4. Sensed signal due to the movement of charged toner particles.

In this case, the charged toner particle passes through the air gap between parallel electrodes. From Eq. (4), q/m can be expressed in the following form:

$$q / m = gd / V. \tag{5}$$

Case 3: $$F_0 > F_1. \tag{6}$$

In this case, the charged toner particle moves from the air gap between parallel electrodes toward the upper electrode.

First of all, let us consider the case when a charged toner particle moves from the air gap between parallel electrodes toward the upper electrode.

As a result, the signal induced in parallel electrodes by the charged toner particle may produce a voltage $v_O(t)$ across the resistor R, and this signal is amplified by the differential amplifier as shown in Fig. 3.

From $i = dq/dt$, $v_O(t) = iR$, we can obtain the charge q of the toner particle (See Fig. 3):

$$q = \frac{1}{R}\int_0^T v_O(t)dt. \tag{7}$$

If $F_0 \geq F_1$ is satisfied, the following relation is obtained from Eqs. (5) and (7):

$$q / m = \{{}^{1}\!/_{mR} \int_0^T v_O(t)dt\} \geq {}^{gd}\!/_{V}. \tag{8}$$

The model of the signal sensed due to a toner particle is shown in Figure 4(a).

Secondly, let us consider the case when massive charged toner particles move from the air gap between parallel electrodes toward the upper electrode. As shown in Fig. 4(b), $V'_O(t)$ is expressed in the following form by summing up $v_O(t)$:

$$V'_O(t) = \sum_{j=1}^{N} v_O{}^j(t - \Delta t_j) \Big/ m_j. \tag{9}$$

From Eqs. (8) and (9), we can obtain the following relation:

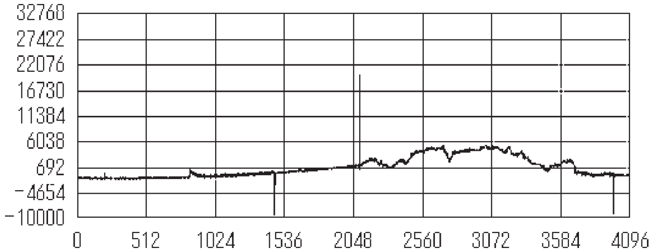


Figure 5. Output signal $V_O(t)$ in the case when V is 1.9[V].

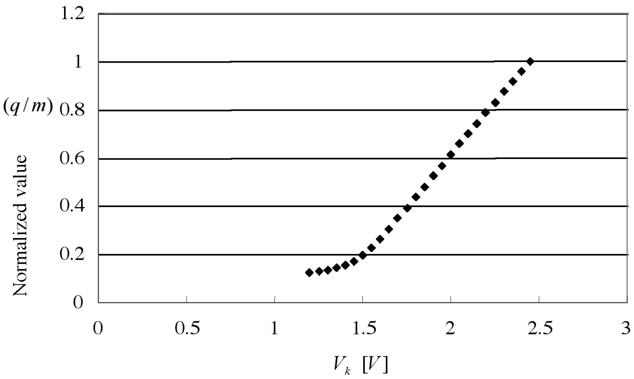


Figure 6. Relationship between V_k and the normalized value of (q/m)

$$\begin{aligned}\sum_{j=1}^{N}(q/m)_j &= \sum_{j=1}^{N} \frac{1}{R}\int_0^T \{v_O{}^j(t-\Delta t_j) \big/ m_j\}dt \\ &= \frac{1}{R}\int_0^T V'_O(t)dt \\ &= \frac{m_0}{R}\int_0^T V_O(t)\,dt \ge \frac{gd}{V}\ .\end{aligned} \quad (10)$$

where

$$V_O(t) = \frac{V_O'(t)}{m_0},$$

and N, Δt, and m_0 are the number of charged toner particles, time delay of charged toner particles, and total effective mass of charged toner particles, respectively.

Thirdly, furthermore, let us consider in the case where the voltage applied across parallel electrodes is increased to the magnitude of V + DV, where DV is the small increase of V. In this case, we can express S(q/m) by the following form:

$$\sum_{\Delta V}\{\sum_{j=1}^{N}(q/m)_j\}_{V+\Delta V} \approx \frac{gd}{(V+\Delta V)}\ . \quad (11)$$

From Eqs. (10) and (11), the difference of S(q/m) is calculated as follows:

$$\left[\left\{\sum_{\Delta V}\sum_{j=1}^{N}(q/m)_j\right\}_{V+\Delta V} - \sum_{j=1}^{N}(q/m)_j\right] \approx \{\frac{gd}{(V+\Delta V)} - \frac{gd}{V}. \quad (12)$$

Experimental System

The schematic diagram of the experimental system for sensing $\Sigma(q/m)$ is shown in Fig. 3. This system consists of the following parts: the four-phase rectangular pulse generator, the sheet printed periodic array conductors for transporting charged toner particles, the DC power source for supplying the voltage to parallel electrodes and the personal computer for analyzing the output signal. The air gap between parallel electrodes is about 1000 μm.

By shifting the electric curtain generated above the periodic array of conductors, the charged toner particles are moved toward the air gap between the parallel electrodes placed as a sensor. The signal picked up by the electrodes is amplified using the differential amplifier. The amplified signal $V_O(t)$ is sent to the analog input of the A-D conversion board in the personal computer as shown in Fig. 3.

Results

Spherical toner particles are used for this experiment. The values of voltage and frequency generated by four-phase rectangular pulse generator are 100 V and 100 Hz, respectively.

Figure 5 shows the output signal $V_O(t)$ of the sensing amplifier in the case when the voltage V applied across the sense electrodes is 1.9 V. In this figure, the induced noise pulses caused by four-phase rectangular pulses are only seen in the output of the amplifier. These are reduced at the last stage of the sensing circuit using a low pass filter.

Figure 6 shows the relationship between voltage V applied across parallel electrodes and the normalized values of $\Sigma(q/m)$ for charged toner particles obtained by applying equation (10). From Fig. 6, the distribution of $\Sigma(q/m)$ for the charged toner particles is calculated by the following equation:

$$\begin{aligned}&\frac{\Delta}{\Delta V}\{\sum(q/m)\} \approx \{\sum(\frac{gd}{V_{k+1}}) - \sum(\frac{gd}{V_k})\}, \\ &k \leftarrow k+1,\ (k=0,1,2\cdots)\ .\end{aligned} \quad (13)$$

Figure 7 shows the relationship between $\Sigma(q/m)$ and the frequency distribution.

From this figure, the distribution of $\Sigma(q/m)$ for charged toner particles of this method has a good coincidence with that measured by E-Spart method near the peak.

Conclusion

A new technique for measuring the value of $\Sigma(q/m)$ for charged toner particles transported above a sheet with periodic array conductors driven by four-phase rectangular pulses has been presented. The parallel electrodes for sensing $\Sigma(q/m)$ for charged toner particles are placed at the end of the flow path in the toner transport system. The sensed signal is amplified by a differential amplifier. By analyzing the signal, the value of $\Sigma(q/m)$ for the toner particles and its distribution are obtained.

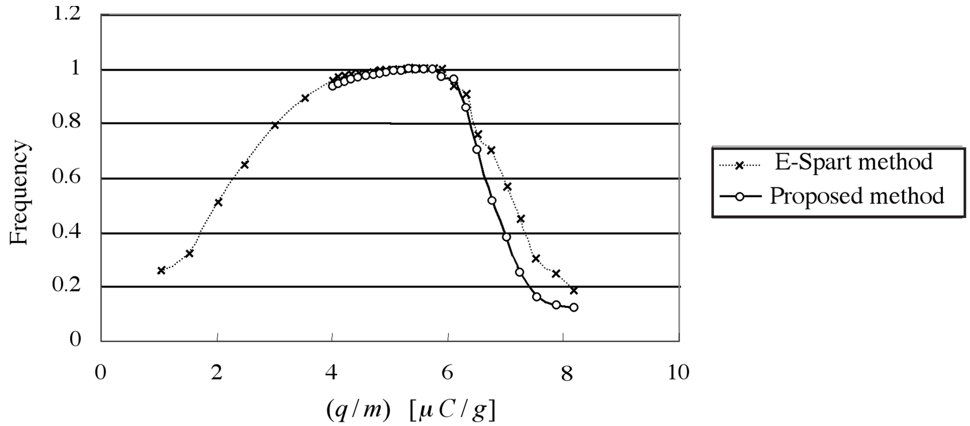


Figure 7. Relationship between (q/m) and the frequency distribution.

From the experimental results, the distribution of $\Sigma(q/m)$ obtained by this method agreement with that obtained by the E-Spart method. The technique shown in this paper can measure easily the value of $\Sigma(q/m)$ and its distribution of the toner particles with on-line use.

Future Work

A method which vibrates the printed sheet of the periodic-array conductors set up on the ultrasonic vibrator is very effective for decreasing the amplitude of the four-phase rectangular pulses.[13] Furthermore, vibrating the lower electrode caused by a piezoelectric element can be used for conventional toner transportation system with on-line use.[14]

References

1. L. B. Schein, *Electrophotography and Development Physics*, 2nd ed., Springer Verlag, Berlin, 1992.
2. N. Kutsuwada, N. Okada, T. Sugai, H. Izawa, Y. Nakamura, S. Sasabe, M. K. Mazumder, and T. Murata, *Proc. IS&T's 8th International Congress on Advances Non-Impact Printing Technologies*, IS&T, Springfield, VA, 1992, p. 126.
3. Y. Yamamoto, K. Taniguchi, H. Yamamoto, and K. Matsubara, *Proc. IS&T's 10th International Congress on Advances in Non-Impact Printing Technologies*, IS&T, Springfield, VA, 1994, p. 165.
4. Y. Yamamoto, K. Taniguchi, Y. Nakano, H. Yamamoto, and Y. Takahara, *Trans. IEE Japan* **119-E**(5), 302 (1999).
5. Y. Yamamoto, K. Taniguchi, Y. Takahara, Y. Nakano, H. Yamamoto, and S. Watanabe, *Trans. IEE Japan* **120-E**(12), 582 (1999).
6. Y. Yamamoto, K. Taniguchi and H. Yamamoto, *Proc. IS&T's 11th International Congress on Advances in Non-Impact Printing Technologies*, IS&T, Springfield, VA, 1995, p. 159.
7. K. Taniguchi, Y. Yamamoto, H. Yamamoto, and J. Mizukami, *Proc. IS&T's NIP12: International Conference on Digital Printing Technologies*, IS&T, Springfield, VA, 1996, p. 519.
8. Y. Yamamoto, K. Taniguchi, K. Fukumoto, H. Yamamoto, and Y. Nakano, *Proc. IS&T's NIP13: International Conference on Digital Printing Technologies*, IS&T, Springfield, VA, 1997, p. 84.
9. K. Taniguchi, Y. Yamamoto, K. Fukumoto, Y. Nakano, S. Watanabe, and H. Yamamoto, *Proc. IS&T's NIP14: International Conference on Digital Printing Technologies*, IS&T, Springfield, VA, 1998, p. 477.
10. K. Taniguchi, S. Morikuni, Y. Nakano, T. Sakai, H. Yamamoto, S. Watanabe, and Y. Yamamoto, *Proc. IS&T's NIP15: International Conference on Digital Printing Technologies*, IS&T, Springfield, VA, 1999, p. 565.
11. F. W. Schmidlin, *Proc. IS&T's 11th International Congress on Advances in Non-Impact Printing Technologies*, IS&T, Springfield, VA, 1995, p. 515.
12. K. Taniguchi, Y. Yamamoto, J. Mizukami, Y. Nakano, S. Watanabe, S. Morikuni, and H. Yamamoto, *Proc. IS&T's NIP14: International Conference on Digital Printing Technologies*, IS&T, Springfield, VA, 1998, p. 473.
13. K. Taniguchi, S. Morikuni, S. Watanabe. Y. Nakano, T. Sakai, H. Yamamoto, T. Yagi, and Y. Yamamoto, *Proc. IS&T's NIP16: International Conference on Digital Printing Technologies*, IS&T, Springfield, VA, 2000, p. 740
14. K. Taniguchi and S. Watanabe, A device for measuring q/m for charged toner particles with vibrating sensing electrode, Application no. 2002-311073A, Japan Patent Office, Oct. 23, 2002.