Some Techniques on Electrostatic Classification of Particle Size

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Abstract

Three kinds of techniques have been developed on electrostatic classification of particle size. The first utilizes linear electrostatic traveling field. A particle conveyer consisted of parallel electrodes was constructed and four-phase traveling electrostatic wave was applied to the electrodes to transport particles on the conveyer. Particles were classified with size under the voltage application of appropriate frequency based on the feature that the direction of particle transport was changed depending on the frequency of the traveling wave and the particle diameter. The second technique utilizes a circular electrostatic conveyer similar with the mass spectroscopy. Particles were classified with size because a locus of the particle in centrifugal field depended on the weight of the particle. The third is the combination of the linear conveyer and an electrostatic separation roller located at the end of the conveyer. Small particles were attached onto the roller charged by a charger roller. These techniques have been expected to be utilized to the classification of the particle size and a charge-to-mass ratio of toner and carrier particles used in electrophotography.

Introduction

Electrostatic traveling-wave transport of particles has been studied and fundamental performances have been clarified by an experimental and numerical investigation, because it has a potential to realize a sophisticated particle supplier in electrophotography.[1,2] The technology will be applied not only for an electrophotography developer[3-13] but also for electronic,[14] chemical, and biochemical applications,[15] because it has the advantage that the transport can be controlled through electrical parameters instead of mechanical means and therefore it is free against contamination of impurities and the mechanical vibration. In addition to these applications, the authors are developing some techniques to classify particle size utilizing the electrostatic traveling wave. Three methods are introduced in this report.

The first one utilizes an interesting finding of the traveling-wave transport experiment that particles were transported in the direction of the traveling wave propagation (forward direction) at low frequency, otherwise at relatively high frequency particles transported backward increased and a transition frequency from the forward to the backward transported region depended on the particle size, i.e., although small particles were transported to the forward direction even at relatively high frequency operation, large particles delayed and moved backward even at lower frequency.[1,2] This feature suggested that particles could be classified with size with the application of traveling wave of an appropriate frequency.

The second method utilizes a principle of the mass spectroscopy. When particles are introduced in circular traveling-wave field created by the electrostatic circular conveyer, particles were classified with size because a locus of the particle depended on the weight of the particle due to the centrifugal force.

The third is the combination of the linear conveyer and an electrostatic separation roller located at the end of the conveyer. Small particles were attached onto the roller charged by a charger roller but large particles fell down from the conveyer, and thus the classification of the particle size was realized.

The effectiveness of these new techniques have been demonstrated with carrier particles used in the magnetic brush development system of electrophotography and these have been expected to be utilized not only to the particle supplier but also to the classification of the particle size and a charge-to-mass ratio of toner and carrier particles used in electrophotography.[16]

Linear System

Experimental Set-Up

A conveyer and a power supply used for the linear classification are shown in Fig. 1.[1,2] The conveyer consists of parallel copper electrodes, 0.5 mm width and 1.0 mm pitch, etched by photolithography on a plastic substrate, 120 mm width and 250 mm length, as shown in Fig. 2. The surface of the conveyer is covered with an insulating film made of acetate rayon (3M, 810-18D) to prevent from electrical breakdown between electrodes.

Traveling-wave propagation is achieved utilizing four amplifiers (Matsusada Precision, HOPS-1B3) and five function generators (Iwatsu, SG-4105), one of which is used to control phase-differences of the other four generators. Rectangular voltage of ±800 V, which is a limit against an insulation breakdown between electrodes, was applied to electrodes.

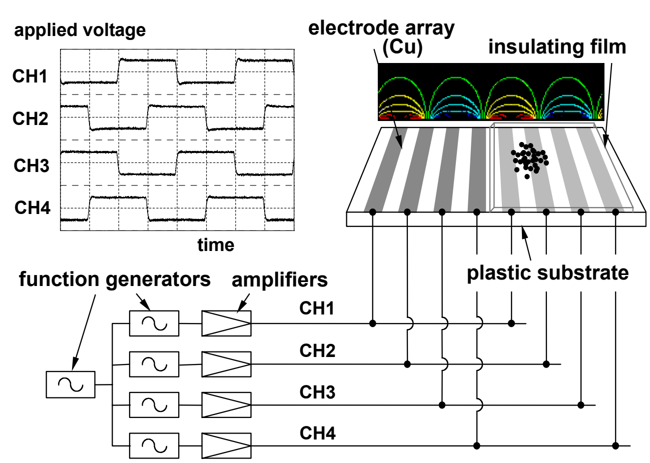


Figure 1. Electrostatic linear particle conveyer and power supply

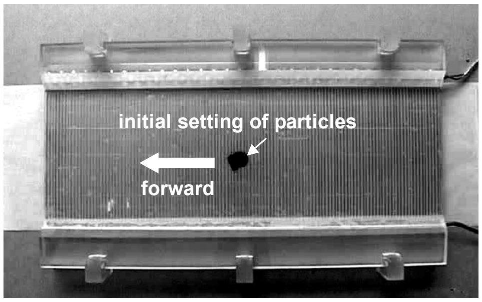


Figure 2. Photograph of linear particle conveyer

Table 1: Specification of Particles

	ACM235	ACM288	ACM2107
averaged diameter, μm	29.7	72.6	106.3
standard deviation, μm	5.3	23.3	13.1
density, 10^3 kg/m^3	3.50	3.62	3.50
resistivity (@10 V), Ωm	1×10^9	3×10^9	8×10^7

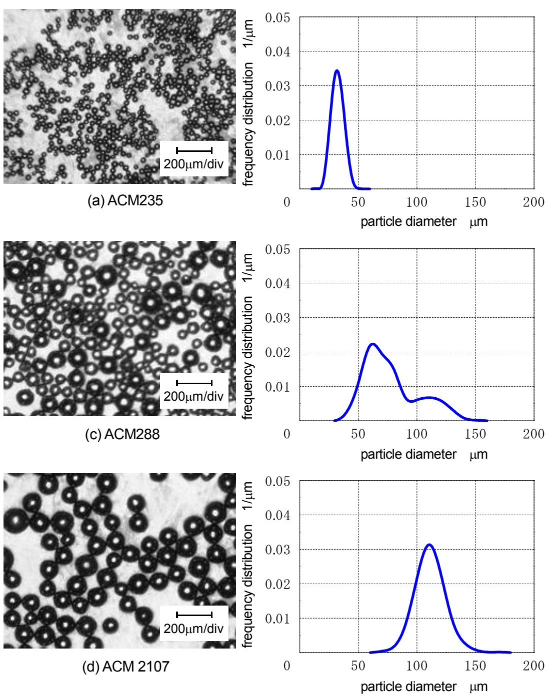


Figure 3. Photograph of particles and distributions of particle diameter

Three kinds of spherical carrier particles made by the polymerization method (Toda Kogyo) were used for experiments.[17-19] Specifications of particles are listed in Table 1 and photographs and distributions of particle diameters are shown in Fig. 3. Distribution of particle diameters was derived by an optical method of randomly selected each 3,000 particles.

Results and Discussion

At low frequency operation, particles were transported to the common direction with that of the traveling wave and the motion was almost synchronized with the wave speed. However, at high frequency some particles delayed to the wave and moved to the opposite direction. To examine characteristics associated with the direction of the particle transport, the following experiments were carried out. First, cloud of 0.5-gram particles was mounted at the center of the conveyer and ±800 V rectangular wave was applied to electrodes. Then we measured the weight of particles transported forward and backward in 30 seconds, where 'forward' is the same direction with that of the traveling wave and 'backward' is the opposite direction.

Figure 4 shows the measured relative weight of forward transported small particles ACM235 and the large particles ACM2107. The results indicated that the relative weight of forward transported particles depended not only on the wave frequency but also on the particle diameter, that is, at an appropriate frequency small particles may be transported forward but large particles may be transported backward. To confirm this hypothesis we prepared mixed particles of ACM235 and ACM2107, the number of each one being the same. Under the condition of the optimum frequency, 140 Hz in this case, a significant classification was realized as shown in Fig. 5. We can also confirm the classification by the photograph shown in Fig. 6.

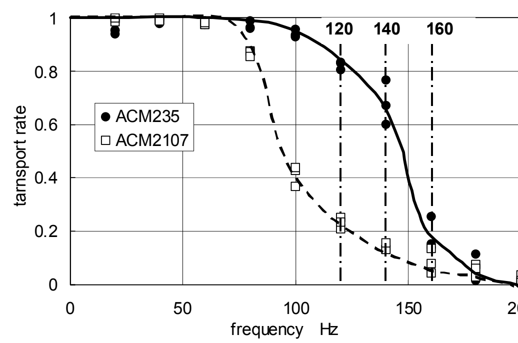


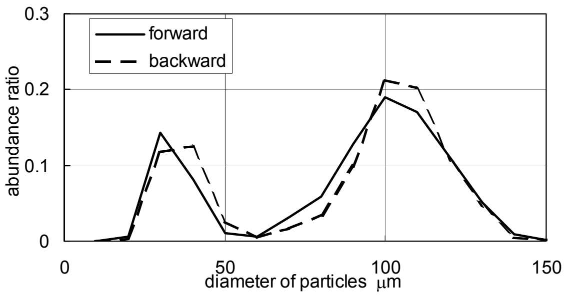
Figure 4. Rate of forward transported particles with respect to frequency of traveling wave

Figure 7 shows another evidence on the particle classification with the particle ACM288 whose diameter was distributed in wide range (refer to Table 1). The classification was also realized as shown in Figs. 7 and 8.

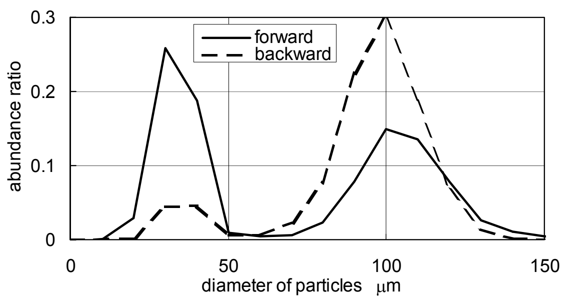
Circular System

Experimental set-up

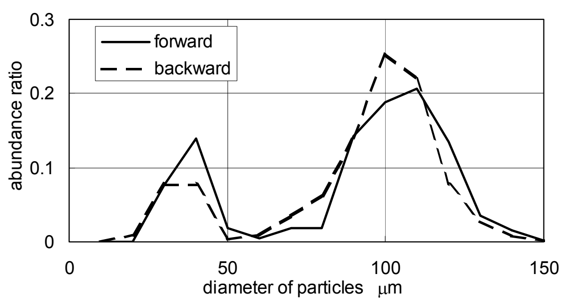
A circular system is based on a principle of the mass spectroscopy. When particles were introduced in circular traveling-wave field created by a circular conveyer shown in Fig. 9(b), particles would be classified with size because a locus of the particle depended on the weight of the particle due to the centrifugal force. The circular conveyer consisted of three segments of a quarter-section electrode shown in Fig. 9(a), 360 mm outer diameter, 240 mm inner diameter and therefore 60 mm effective width. The width and pitch of electrode were 1.0 mm and 2.0 mm, respectively, at the inner circumference and 1.5 mm and 3.0 mm at the outer circumference. Particles used for experiment was the same with those used for the linear system, i.e., mixed of the small particle ACM235 and the large particle ACM2107. Particles were settled initially on the end of the circular conveyer as shown in Fig. 9(b) and then four-phase electrostatic traveling wave, rectangular of ±800 V, was applied to the electrodes.



(a) 120 Hz

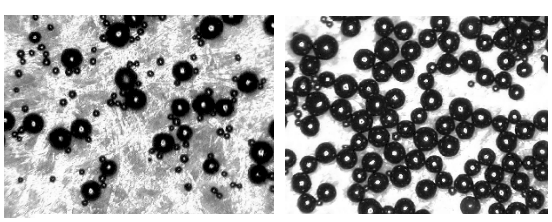


(b) 140 Hz



(c) 160 Hz

Figure 5. Distributions of particle diameter in forward and backward transported particles (ACM235+ ACM2107 mixed particles)



(a) forward transported **(b) backward transported**

Figure 6. Photographs of forward and backward transported particles (ACM235+ACM2107 mixed particles, 140 Hz)

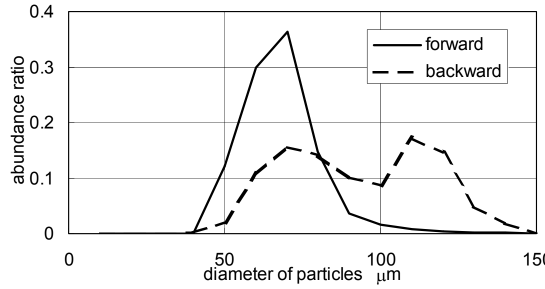
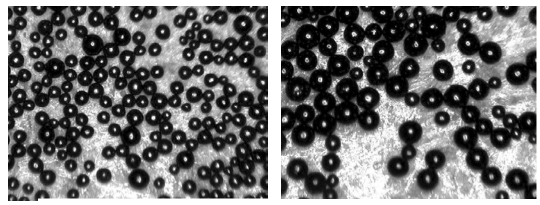
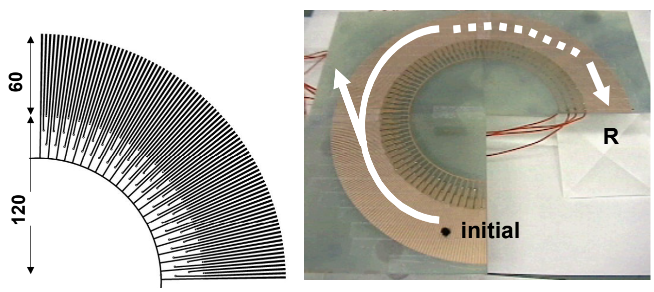


Figure 7. Distributions of particle diameter in forward and backward transported particles (ACM288, 140 Hz)



(a) forward transported **(b) backward transported**

Figure 8. Photographs of forward and backward transported particles (ACM 288, 140 Hz)



(a) 1/4 segment **(b) circular conveyer**

Figure 9. Centrifugal circular separation conveyer

Results and Discussion

At the first place, the optimum frequency for the classification was investigated. Figure 10 shows abundance ratio of particles reached at the end of the circular conveyer, a portion marked 'R' in Fig 9(b). The classification was most effective at 25 Hz.

Figure 11 shows the measured relative number of circulated particles that reached to the other end of the conveyer at the optimum frequency, 25 Hz, operation. We can see that large particles were circulated and reached to the end of the conveyer and small particles were flicked out of the conveyer, and thus the classification was achieved.

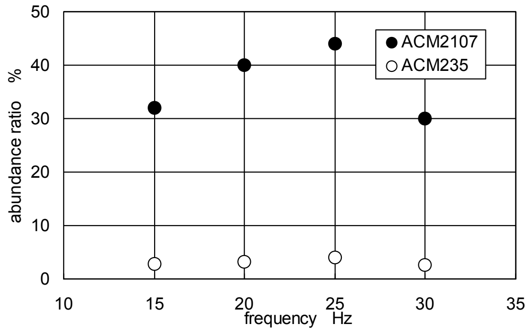


Figure 10. Performance of classification with respect to frequency - abundance ratio of designated particles reached at the end of the conveyer (ACM235+ ACM2107 mixed particles)

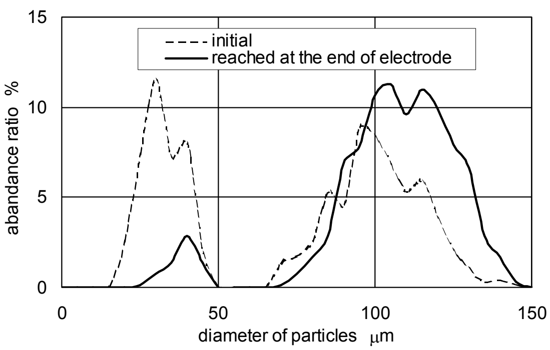


Figure 11. Distributions of particle diameter in initial and circulated particles (ACM235+ ACM2107 mixed particles, 25 Hz)

Roller System

Experimental set-up

The last is a roller system that utilizes the balance of Coulomb force and the gravitational force. It was composed of two parts. One was a parallel electrode array that transported particles by virtue of the electrostatic traveling wave, the same as the linear conveyer, and another was a charged separation roller located on the upper side of the array, 2 mm gap to the conveyer, as shown in Figs. 12 and 13. Particles mounted on the left side of the linear conveyer were transported to the right side where the separation roller was approximated. Particles used for experiment was the same with those used for the linear system and the circular system, i.e., mixed of the small particle ACM235 and the large particle ACM2107. Because the Coulomb force is larger than the gravitational force for small particles, small particles are attached to the roller but, on the other hand, large particles are run over from the right end of the linear conveyer. Thus the electrostatic classification of particle size is realized.

In this system, a biased charger roller was used to charge the separation roller.[20,21] The charger roller consists of a center shaft made of steel and electroresistive elastmer bulk rubber (outer diameter: 11.5 mm). The roller was in contact with the separation roller (outer diameter: 30.0 mm) and micro-discharge controlled the charge of surface insulation film on the separation roller after charge cancellation by attached particles, repeatedly. The surface charged voltage *V* of the separation roller due to micro-discharge is determined by the Paschen's law.[20]

$$V = (\sqrt{6.2d/\varepsilon_r} + \sqrt{312})^2 \qquad (1)$$

where d (μm) is the thickness of the insulator film on the separation roller, 110 μm and ε_r was the relative dielectric constant, 3.0.

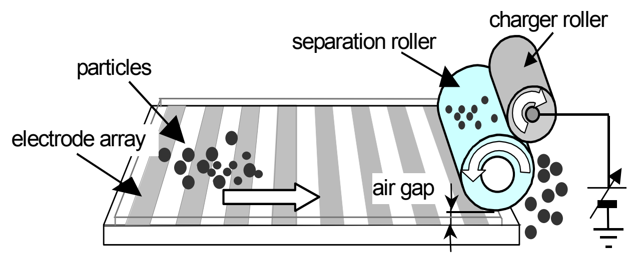


Figure 12. Roller separation system

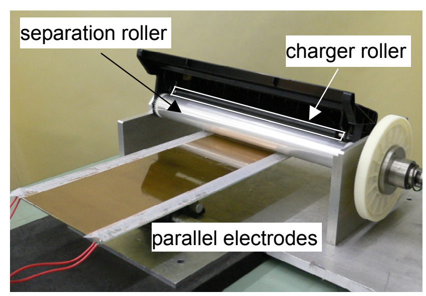
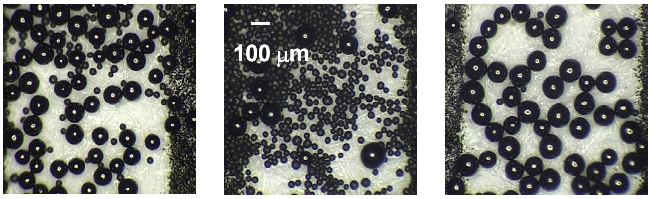


Figure 13. Photograph of roller separation system

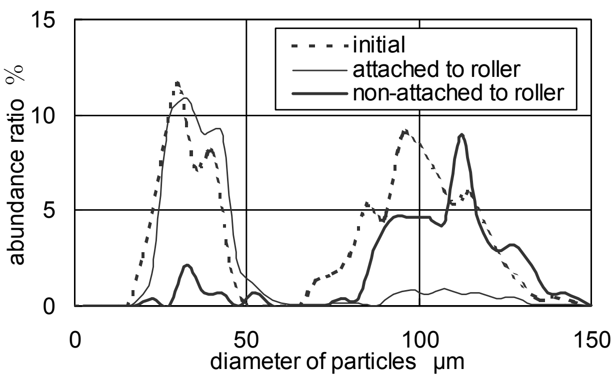
Results and Discussion

Figure 14 shows photographs of initially settles particles, particles attached to the roller, and particles non-attached to the roller and run over from the right end of the linear conveyer, in case of 1.0 kV surface potential on the separation roller. In this experiment, low-frequency wave, 5 Hz, was applied to the linear conveyer, because transport of particles was almost synchronized with the traveling wave at this frequency. Because particles were charged on the parallel electrodes due to the static contact and friction to the insulation film on the conveyer,[2] small particles were attached electrostatically on the separation roller against the gravitational force. This feature was evaluated quantitatively as shown in Fig. 15(a). Figure 15(b) shows the result in case of 0.5 kV surface potential on the separation roller. Sufficient classification of particles size was also demonstrated, although the performance was less than or comparable to the case of 1.0 kV surface voltage. It will be susceptible to optimize design and operational parameters, such as frequency of the traveling wave, traveling length that determines charge of particle, surface voltage, gap, and rotational speed.

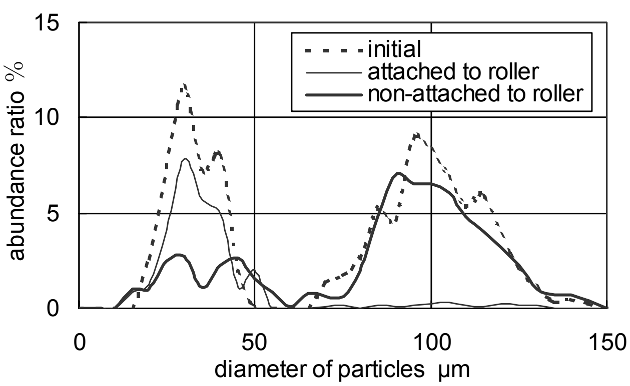


(a) initial (b) attached to roller (c) non-attached

Figure 14. Photograph of initial, attached to the roller, and non-attached particles (ACM235+ ACM2107 mixed particles, 25 Hz, surface potential on separation roller: 1.0 kV)



(a) surface potential on separation roller: 1.0 kV



(b) surface potential on separation roller: 0.5 kV

Figure 15. Distributions of particle diameter in initial, attached to the roller, and non-attached particles (ACM235+ ACM2107 mixed particles, 25 Hz)

Concluding Remarks

Three techniques have been developed on electrostatic classification of particle size.

1. The first one utilizes linear electrostatic traveling field. Four-phase traveling electrostatic wave was applied to the particle conveyer consisted of parallel electrodes to transport particles on the conveyer. Particles were classified with size under the voltage application of appropriate frequency based on the feature that the direction of particle transport was changed depending on the frequency of the traveling wave and the particle diameter.
2. The second technique utilizes a circular electrostatic conveyer similar with the mass spectroscopy. Particles were classified with size because a locus of particle in the centrifugal field created by the circular conveyer depended on the weight of the particle.
3. The third is the combination of the linear conveyer and an electrostatic separating roller located at the end of the conveyer. Small particles were attached onto the roller charged by a charger roller as a balance of the Coulomb force and the gravitational force.

These techniques have been expected to be utilized to the classification of the particle size and a charge-to-mass ratio of toner and carrier particles used in electrophotography.

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