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Some techniques on electrostatic separation of particle size utilizing electrostatic traveling-wave field

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Abstract

The author has developed five kinds of techniques on electrostatic separation of particle size utilizing the balance of the electrostatic and gravitational force. The first is an inclined plate conveyer system. A plate conveyer consisted of parallel electrodes was constructed and four-phase electrostatic traveling wave was applied to the electrodes to transport particles on the conveyer. Particles were separated with size under the voltage application of appropriate frequency based on the feature that small particles were transported upward against the gravity but large particles were apt to fall down. The second technique is an inclined tube system. The principle is common with that of the inclined plate system. The third technique utilizes a circular electrostatic conveyer similar with the mass spectroscopy but utilizes the feature that small particles fly high altitude compared to that of the large particle. The forth technique, a vortex system, also utilizes the difference of flying locus of small and large particles. The last technique 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. Although the yield was reduced to realize the high separation performance with the former four techniques, relatively high yield was realized without reducing the separation performance with the roller system. This technique is expected to be utilized to the separation of toner and carrier particles used in electrophotography.

Keywords: Traveling wave; Electrostatic force; Electrophotography; Toner; Carrier

1. 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 electrophotographic developer [3–13] but also for electronic [14], chemical, biochemical [15,16], and space applications [17], because it has the advantage that the transport can be controlled through electrical parameters instead of mechanical means and it is almost free against acoustic noise, mechanical vibration, and contamination of impurities.

In addition to these applications, the author is developing some techniques to separate particle size utilizing the electrostatic traveling wave [1], because the distribution of particle size must be narrow to realize high-quality images in color laser printers [18–21]. Although conventional mechanical methods such as a sieve and a cyclone have been employed for the industrial separation of particle size, these have demerits that particles are damaged by the mechanical force and contaminated with impurities such as dust, metal fragments, and oil mist. With respect to the electrostatic method, the electrostatic separation has been widely used for the dry separation of small parts and fragments based on the electric force acting on charged mass in the electrostatic field [22,23]. However, the technology is not applied for the separation of particle size but for mineral processing, removal of foreign substances in food industry, composite refinement, and recycling of resources [24].

In this report we have introduced five separation methods utilizing the electrostatic traveling wave and studied feasibility of these methods. The effectiveness of

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these techniques have been evaluated with small carrier particles used in the magnetic brush development system of electrophotography [18–21] and some of these technologies have been expected to be utilized not only to the particle supplier but also to the separation of the particle size and a charge-to-mass ratio of toner and carrier particles used in electrophotography [18].

2. Inclined linear system

2.1. Experimental set-up

The first method utilizes a balance of the electrostatic force and the gravitational force. An electrostatic conveyer is inclined in θ to the horizontal position. It is expected that small particles are transported upward by the electrostatic traveling field such that particles move up the incline, but large and heavy particles roll down at the condition that the electrostatic force applied to the particle is smaller than the gravitational force.

A conveyer and a power supply used for the inclined linear separation system are shown in Fig. 1 [1,2]. The conveyer consists of 125 parallel copper electrodes, 1.0 mm width and 2.0 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 (40 μm thickness, 1.3 relative permittivity, 3 M, 810-18D) to prevent from electrical breakdown between electrodes. A limiting voltage against the insulation breakdown was 800 V. Particles are tribocharged in contact with the film.

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 was applied to electrodes, because it is the most efficient for the particle transport [1].

Spherical particles made by the polymerization method (Toda Kogyo) were used for experiments [1,2,19–21].

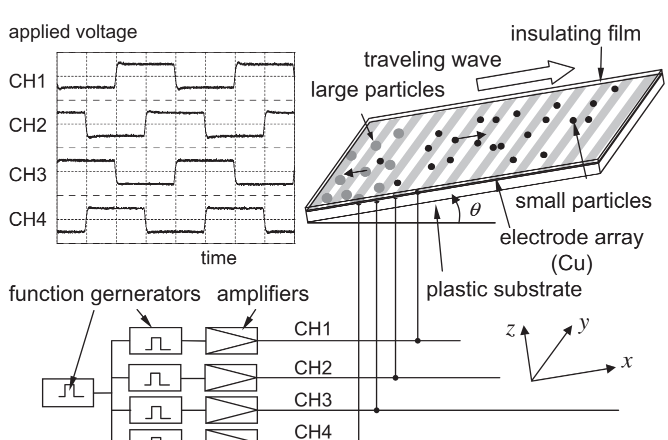

Fig. 1. Inclined plate-type electrostatic particle separation system and power supply.

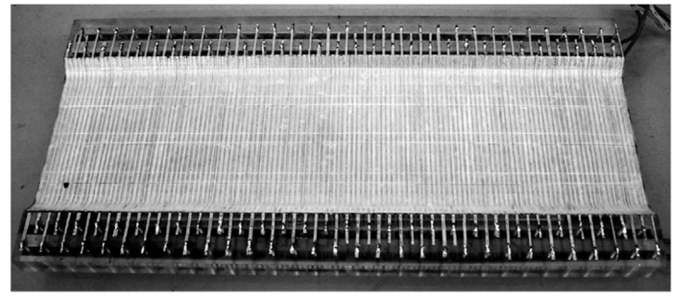

Fig. 2. Photograph of plate-type electrostatic conveyer.

Particles, originally manufactured for carriers of a two-component magnetic brush development system in electrophotography, were made of phenol resin. Distribution of the particle diameter, derived by an optical method of randomly selected each 3000 particles, is shown in Fig. 3, designated in dark curves and cited as 'initial.' An averaged diameter is 73 μm, but two peaks exist at 65 and 100 μm. The density is $3.62 \times 10^3\,\mathrm{kg/m^3}$ and the resistivity is $3 \times 10^9\,\Omega\,\mathrm{cm}$ measured at 10 V applied voltage with an aggregated sample. Particles were placed on the conveyer without prior charging.

It has been reported that particles were transported almost linearly with time, even when particles were placed on the conveyer without prior charging [2]. It has been clarified that particles were slightly charged when they were settled on the conveyer due to the static electrification. If the traveling field was applied, the Coulomb force and dielectrophoresis force were applied to particles and then particles were driven and collided with each other and with the conveyer. This increased charge and polarization with time. The Coulomb force was the predominant force to drive particles except when particles were on the conveyer.

2.2. Results and discussion

Fig. 3 shows measured diameter distributions of initially settled particles on the lower end of the conveyer and particles reaching the top end of inclined plate conveyer. Particles were collected on a sheet of charta settled at the top end of the conveyer. The applied voltage, the inclination of the conveyer, and the frequency of the applied voltage were experimental parameters. The ordinate of the figure designated the abundance ratio defied as the percentage of particle numbers reached to the top end of the conveyer to the initially settled number of particles on the lower end of the conveyer. The particle separation is not clear, but in the case that the frequency was higher than 60 Hz, particles that reached to the top end of the conveyer contained almost no large particles larger than a certain diameter that is determined by the applied voltage and the inclination of the conveyer. That is, it is possible to eliminate large particles by this inclined linear system like a screener. On the other hand, a yield of the separated particles was low at the condition that the separation