Measurement of electric charges on flowing toner with an electrostatic voltmeter

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Abstract

In every electrophotographic development system, the optimal charging and mass transfer processes are crucial for achieving high quality prints. Therefore, precise measurements of both charge and mass of toner become very important. This paper presents a novel method for measurements of the electric charge of the flowing electrophotographic toner particles. An electrostatic voltmeter (ESVM) is used for precise measurements of the voltage induced by charges carried by the flux of solid toner particles and by the charges generated on the walls of a dielectric pipe, while the toner is pneumatically transported through the pipe. Additionally, the total charge and mass of the toner are measured before and after passing through the pipe. In this way, voltages registered by the ESVM can be correlated with the amount of charge created by tribocharging. This allows for determination of tribocharging properties of the toner at a given particle flow velocity and for a given dielectric pipe material. The ESVM is a convenient, non-contacting, continuous, real-time charge monitoring tool.

Introduction

Measurements of electric charges on particulate materials in motion are of interest for many industries. Pneumatic transport of powdered media has been extensively investigated by many researchers [1, 2, 3]. Triboelectrification creates charges not only on moving particles, but also on the elements of the duct system through which the flowing particulates are conveyed. Electrophotography is one of the areas where information on charging phenomena, especially these related to toner particles, is extremely important. This paper presents a simplified flowing charge measurement method that can be used for examination of toner charging. This technique utilizes an electrostatic voltmeter (ESVM) and two Faraday cups that are used to evaluate and interpret ESVM readings. The basic idea of the measurement is shown in Figure 1. This is a simplified representation of the toner particle flow through a pipe. The Coulomb potential V_2 generated on the ESVM probe by the moving charge q is:

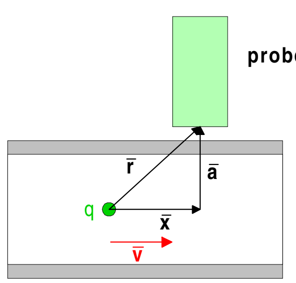


Figure 1: Simple model.

$$V_2 = \frac{q}{4\pi\epsilon_0\epsilon \cdot r} = \frac{q}{4\pi\epsilon_0\epsilon}\frac{1}{\sqrt{x^2+a^2}} \quad (1)$$

The total charge influencing V_2, however, is a result of charge carried by the flowing particles and the charge induced on the pipe. The setup shown in Figure 2 allows for separation of these two factors. The charge of the toner before and after it flows through the pipe can be measured by use of two Faraday cups. Knowing the voltage displayed by the ESVM as well, it is possible to evaluate the charging effects that take place in the pipe in a qualitative way. Based on results of this evaluation, a flowing charge measurement apparatus is proposed. This kind of setup can possibly simplify in-line flowing charge measurements for the benefit of the electrophotographic industry.

Measurement setup

Toner media used for tests

A two-component toner N20-02, Imaging Society of Japan, toner concentration 5 ± 0.2 % wt., maximum Q/m ratio of -18.2 ± 2.4 μC/g. Tests conducted with this toner composition did not require separation of the toner particles from the carrier.

Equipment

- oscilloscope Tektronix TDS 5104B,

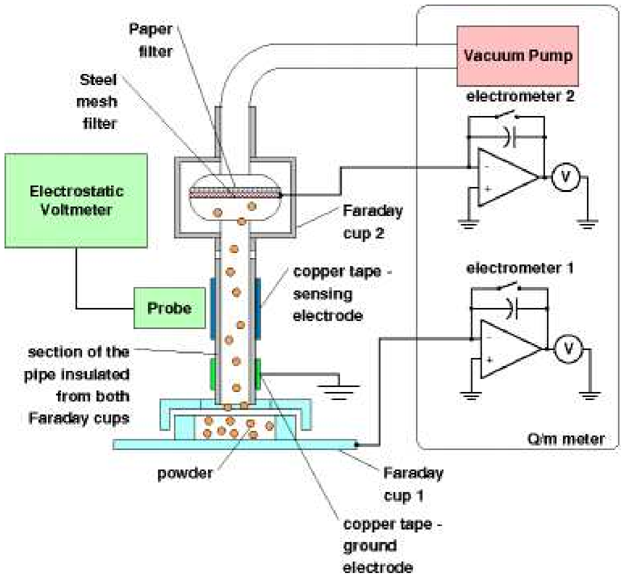


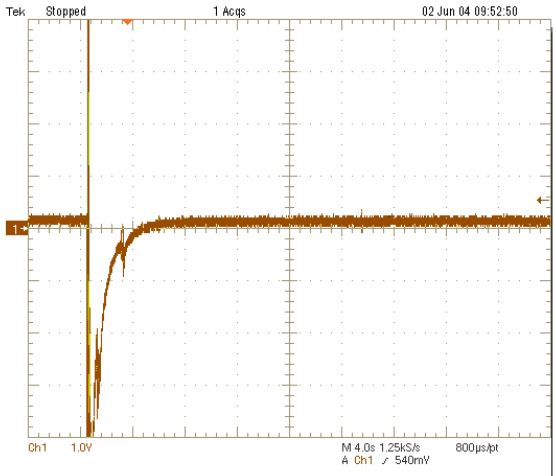
Figure 2: *Test setup.*

- Trek 210HS charge-to-mass ratio measurement system, equipped with two electrometers as standard,
- Trek electrostatic voltmeter with a speed of response of 5 ms per 10 V step voltage,
- A dielectric pipe made of phenolic epoxy (volume resistivity $10^{13}\Omega \cdot \mathrm{cm}$, surface resistivity $10^{8}\Omega$, relative dielectric permittivity $\epsilon = 4.9$, internal diameter 6 mm, outside diameter 8 mm, total length 64 mm, the copper tape sensing electrode is at the distance of 20 mm from the ground electrode),
- Mettler Toledo PR1203 scale, accuracy of ± 1 mg

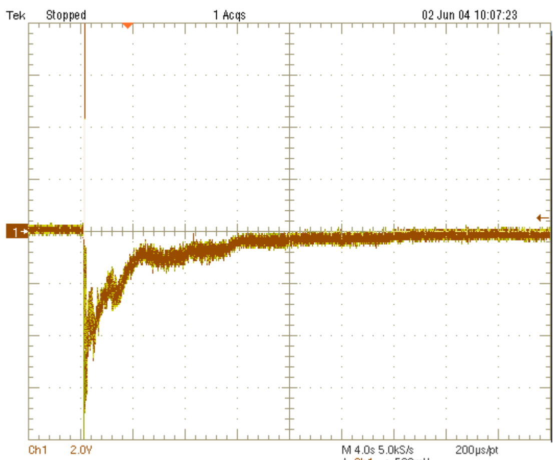
The proposed test setup is shown in Figure 2. An electrostatic voltmeter sensor was placed at the distance of 0.5 mm from the 27 mm wide copper tape ring. The sensor diameter was 3 mm. The ESVM was zeroed before each test. The copper tape on the pipe was grounded and the zero-control on the ESVM was adjusted to show zero volts.
First test conducted with the above mentioned setup was to find out whether the dielectric pipe becomes charged due to an air flow alone. It has been confirmed that there is no charging effect due to the air flux passing through the pipe. The air volume flow rate was constant for all experiments, and established at 28 liters/min. All the tests were conducted at 45-50 % RH and 20-22 $^{\circ}$C.
Next set of tests was conducted with a two-component toner. The toner mix (toner plus carrier) was weighted and put into the Faraday cup 1. The net charge of the toner composition was then recorded. The powder mix was then drawn through the pipe and collected in the Faraday cup 2. During that process, the charge in both cups along with the ESVM voltage were recorded. The Faraday cup 1 and 2 were weighted to find the amount of toner composition which passed through the pipe.

Results

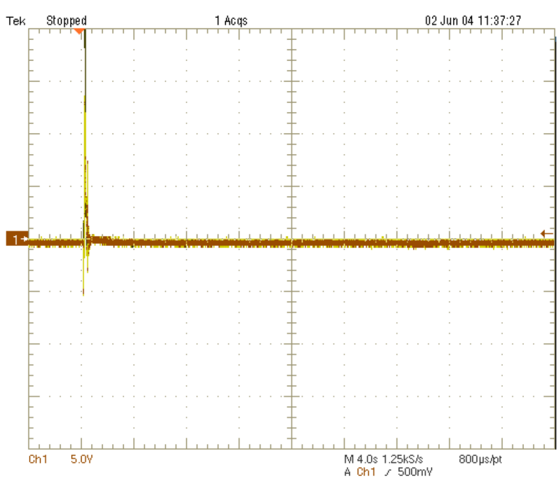
The toner composition Figure 3(a) presents a signal recorded by the electrostatic voltmeter for 43 mg of toner mixture particles flowing through the pipe. Initially the powder was not charged - as indicated by the electrometer 1, and after it passed through the pipe it acquired a charge of 2 nC. This means that the Q/m ratio for the composition rose to 41 nC/g.
The next set of tests involved measurements on the toner composition purposely charged to various charge levels. This was done by applying a DC voltage to the inner section of the Faraday cup 1 with the electrometer 1 disconnected from the cup. The toner mixture was charged using various voltage levels, as supplied from the DC power supply. The voltages were +1500, +1000, +500, -500, -1000, -1500 V, respectively with the charging time of 30 s. In this way the toner powder acquired certain amounts of electric charge that was measured after the cup was connected again to the electrometer. Figures 3(b) and 3(c) present resulting oscillograms for toner charged with +1500 V and -1500 V applied during the charging process. In the first case, 1.211 g of toner was initially charged to 5 nC, giving 4.2 nC/g of Q/m ratio. 94 mg of the toner was collected in the Faraday cup 2 with a net charge of 2 nC. This gives Q/m ratio of 21.3 nC/g. For the toner that was initially charged with -1500 V, the initial Q/m ratio was -7.1 nC/g and after passage through the phenolic pipe this ratio became -50 nC/g.
Figure 4(a) presents an expanded view of the initial voltage peaks for toner not charged (Figure 3(a)), for the time between 4.9 and 5.2 s of measurement. Figure 4(b) shows the same kind of zoom in the time scale for the measurement done with toner charged positively (Figure 3(b)). Figure 4(c)presents the voltage oscillogram data expanded between 8.2 and 10 s for the toner charged with negative voltage (originally shown in Figure 3(c)).



(a) Toner composition not charged, time scale 4 s/div, voltage scale 1 V/div.

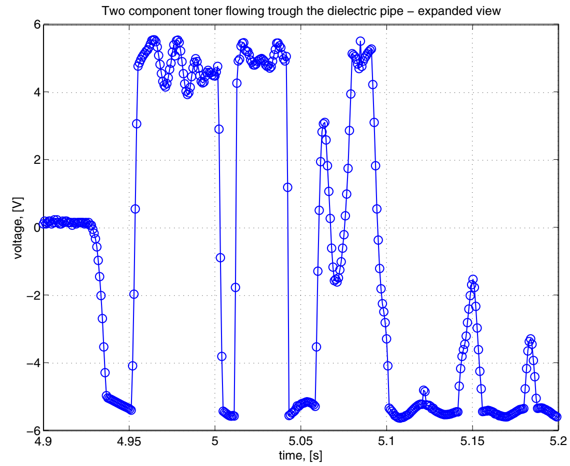


(b) Toner composition charged with +1500 V, time scale 4 s/div, voltage scale 2 V/div.

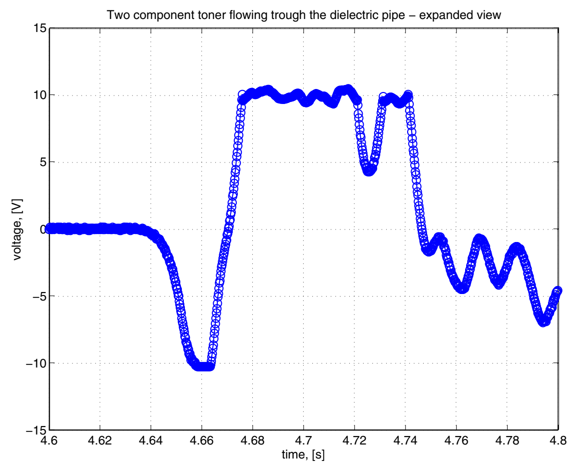


(c) Toner composition charged with -1500 V, time scale 4 s/div, voltage scale 5V/div.

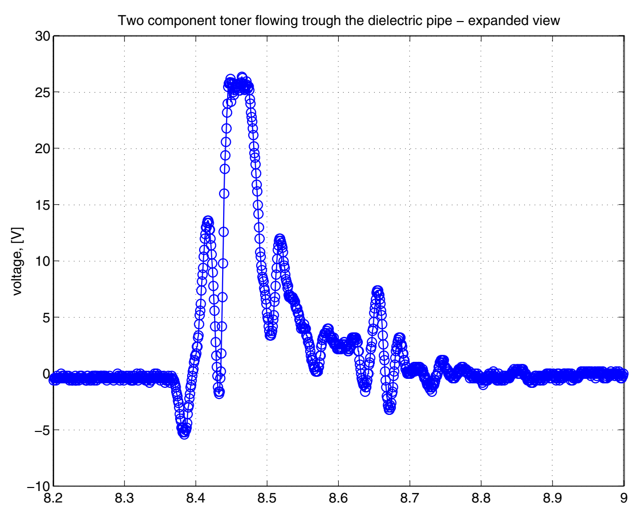
Figure 3: *The voltage induced on the electrode with the toner flowing through the pipe.*



(a) Toner not charged



(b) Toner charged with +1500 V.



(c) Toner charged with -1500 V.

Figure 4: *Expanded oscillogram of the induced voltage for the toner flowing through the pipe.*

Discussion and conclusions

Results of experiments show that the investigated toner mixture, even though initially not charged, became electrically charged during its passage through the dielectric pipe. The electrostatic voltmeter monitored voltage induced on the copper tape ring. This voltage was the result of the flow of charges carried by the toner and the air flux, as well as of the charges induced on the surface of the pipe. Tests conducted with the air alone flowing through the tube did not indicate that there was a charging of the pipe due to the air flux. The majority of the powder was drawn through the nozzle right after the pump was turned on. This fact showed up on the oscillogram (Figure 3(a)) as an initial voltage peak. Figure 4(a) presents an expanded view of that initial peak for not charged toner. The oscillogram shows voltage oscillation caused, most probably, by the transfer of charges between the pipe wall and flowing particles as the powder collides with the wall. At the same time the electrometer 2 recorded a rapid increase in the collected charge value. The voltage then reversed quickly its polarity and relatively slowly decayed toward zero. This effect was most probably due to the charge created on the pipe by the passing toner (combination of tribocharging and induction). The charge induced on the sensing copper ring electrode was then quickly dissipated and/or neutralized, as shown in Figure 3(a)). The voltage displayed by the ESVM after the discharge was found to be fairly stable at a fixed level, and the charge indicated by the electrometer 2 remained constant. This could mean that there were no powder particles flowing through the tube, even though the air was still flowing through the pipe. When the airflow was turned off, there was no change in the voltage displayed by the ESVM. This voltage decay characteristic, recorded after particles went through the tube, can possibly be characterized by a well known dependence:

$$V_{20} = V_2 \cdot e^{-\frac{t}{RC}}, \tag{2}$$

where R is the resistance between the test electrode and ground (and its value was calculated from the geometry of the pipe as $\sim 125\mathrm{M}\Omega$), C is the capacitance of the pipe, V_{20} is the voltage recorded by the ESVM after the time t, V_2 is the initial voltage remaining on the tube after the passage of the powder particles through the pipe. Assuming that the equation 2 applies to this test, the capacitance of the test electrode is calculated at 2.7 nF, using the values of voltages and time provided by the oscillogram 3(a). An electric charge induced on the detecting electrode can be calculated using formula [4]:

$$q = 4\pi\epsilon_0\epsilon \cdot \sqrt{v^2t^2 + r^2} \cdot V_2(t) \tag{3}$$

When toner was initially charged, the observed initial voltage peaks were significantly higher comparing to results obtained with toner that was not charged. In case of positive initial charge the initial voltage peak was 11.2 V, for the negative charge it was 27.5 V. It had been found that the Q/m ratio in both cases increased after the toner passed through the dielectric pipe. Results of experiments presented in this paper indicate that the electric charges created on the dielectric pipe due to flow of toner, regardless whether toner particles are initially charged or not, can be observed and monitored with an electrostatic voltmeter.

References

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Biography

Maciej A. Noras is a R&D engineer at Trek, Inc. He received his M.S. degree in Electrical Engineering from the Wroclaw University of Technology in 1994 and Ph.D. in Engineering Science from the Southern Illinois University at Carbondale in 2000. His Masters thesis was honored with awards from Polish Committee of Materials for Electrotechnics and from Polish Electrical Engineers Association. His research is focused on materials science (high T_c superconductors, piezoelectrics, electrorheological fluids) as well as on high voltage technology and electrostatics (pulsed power plasma technology, electric fields and charge detection).

David M. Zacher received a B.S. in Electrical Engineering from the University of Rochester in 1992 and an M.S. in Electrical Engineering from SUNY at Buffalo in 1995. He began his career at Trek Incorporated in 1994 as a Sales Engineer focusing on Trek's European Business. He then worked for six years as an R&D engineer for Eastman Kodak and Heidelberg Digital. In 2003, he rejoined Trek as a Sales Engineer specializing in Electrophotographic and High Voltage Amplifier applications.