Toner Current Discharge on Conductive Surfaces and Its Use in Charge Level Control

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Abstract

Toner discharge current from conductive roller surfaces was measured revealing a useful means to study the toner charging mechanisms and providing a mechanism for real time control of toner charge and layer thickness. Single component resistive toner in a high speed toner applicator system was charged by ion bombardment using the field charging process. The charged toner is delivered to the electrostatic image by two conductive rollers in the development system. Significant amounts of the toner's net charge was measured as being dissipated to electrical ground on the roller surfaces. Discharge to both system rollers showed a loss of over 30% of the net charge at each roller and toner surface voltage measurements correlated with these measurements. The effect was found to be dependent on system surface speed, toner charge levels, and dependent with time on the change of the toner charge, a function of the tribo-charging properties of the toner. Analysis of the discharge current with time reveals the properties of the two charging mechanisms involved in the process:

1. The rapid positive charging caused by ion bombarded field charging.
2. The slower acting negative tribo-charging, an effect resulting from the toner interaction with the system's conductive rollers.

The resulting measured discharge from the toner can be converted into a useful controlling signal to maintain constant toner characteristics. Such control can maintain the toner charging level and the toner layer thickness on the system rollers using a feedback loop to control the electrical biases on the toner delivery rollers or the driving corona voltage.

Introduction

Toner charge level stability in an electrostatic non-impact printing system is an important factor in maintaining image consistency. Control over such stability is difficult, particularly during cold system starts and also as components show a degree of change with aging. The toning system must either demonstrate a wide enough performance window to show consistent performance with aging or the system must be controlled appropriately by sensing charge levels and applying the necessary control to maintain consistent imaging performance.

A single component non-magnetic toning system[1,2] was developed for use in a high speed electron beam imaging system.[3] The development system is based on a field charging (corona charging) process[4] on toner in a fluidized bed. The levitated toner particles are bombarded by ions generated from corona sources within the fluidized bed. In the presence of the electric field, the particles reach a saturation charge level, Q_{max}, which is dependent on the toner particle size, relative permittivity, and the local electric field. The saturation charge level is commonly known as the Pauthenier limit and is defined by the equation:

$$Q_{max} = 4\,\pi\,\varepsilon_o\,r^2\,p\,\mathbf{E} \tag{1}$$

where r is the particle radius, p is a dimensionless constant based on the relative permittivities of the toner and surrounding gas [$p = 3\kappa_t/(\kappa_t + 2)$], and **E** is the local electric field strength.

The field charging mechanism is a very rapid one and is mostly dependent on the density of ionization from the corona and the mobility of the ions. In a general form, the charging mechanism can be expressed in the following form,

$$Q_{field} = Q_{max}\,[1/(1 + t/\tau)], \tag{2}$$

where τ is the time constant or time for a particle to reach 1/2 Q_{max}. This constant is dependent on the ionization parameters described above, but is also dependent on the mobility of the toner particles in the fluidized bed. An exact expression has not been found, but given similar conditions of coronal output, toners with better free flowing characteristics reach Q_{max} much more quickly than those with marginal flows. Normal time constants associated with field charging range from 0.1 to 5.0 seconds. In the experiments, using a corona at +7.0 kV, standard resistive 12 µM toner approaches a Q/M level approaching +35 to + 40µC/gm within seconds after enabling the corona voltage.

A second mechanism of toner charging in the system involves triboelectric charging as the toner is scraped from the delivery rollers in the developer unit. To insure that the developed toner layer remains uniform, the residual toner is totally scraped from the rollers on each rotation by scraper blades against both of the delivery rollers. The tribo-charging occurring in the development system charges the toner negatively. Tribo-charging is a time dependent function dependent on the following relationship:[5]

$$Q_{trib} = -Q_{trmax}\,[1 - \exp(-t/\tau)] \tag{3}$$

The maximum charge achievable by triboelectrification, Q_{trmax}, is a variable dependent on the toner and additive materials, roller material, and the operational speed of the unit. The variable t is time and t is the charging system time constant dependent on the mobility of the toner in the fluidized bed, the roller operating speed, and the amount of toner in the fluidized reservoir.

Triboelectric charging of the toner is a slower process than the field charging mechanism with time constants in ranging from 10 to 1000 seconds. Tests on charging levels using iron carrier systems in a Vertex Tribo Tester show charging levels in the range of -15 to -20 µC/gm.

Net charge level on the toner is manifested by the performance characteristics and measurements made on the developing system and can be described by the combination of the field charging mechanism and the tribo-charging mechanism:

$$Q_{tot} = Q_{field} + Q_{trib} \tag{4}$$

As the time t approaches a large value, the total charge asymptotically approaches a stability level which is determined by the maximum levels of the field and tribo-charging mechanisms. The transition period from t = 0 until the stability level is reached is governed by Equation 4 with two different time constants and two different maximum charge levels. It is a period in which the charge level on the toner changes, the toner layer on the roller (M/A) changes, and the optical reflection density of the developed image changes. Typically, with the toner formulation of choice, stability is achieved in 200 to 250 seconds. During this period, the development system creates overly dense images and is prone to random dusting in background areas. Bench testing on the toner performance has also shown alternate measurements which correlate with Equation 4 and the also the imaging performance.

An instrumented development system as shown below in Figure 1 is typically used in toner performance measurements. This test system utilizes the standard dual roller system with a switchable bias voltage supply to allow measurement of the toner parameters on either roller. A forward field of 2.2 V/µM from the first system roller (transfer roller) to the second roller (applicator roller) transfers the majority of the toner layer over to the applicator roller where measurements are performed. A reverse field of similar magnitude retains the toner layer on the transfer roller where like measurements are performed.

Toner layer voltage measurements with a non-contact electrostatic voltmeter on the two system rollers provided an interesting result. The layer voltage on the second system roller was measured to be significantly lower than on the first roller. A significant amount of charge was being lost from the toner to the system. The only contact that the resistive toner had to any system component was its contact with the first system roller or transfer roller. Since the rollers are conductive and provided with an electrical path to ground, it was suspected that the charge was being lost while the toner is in contact with the conductive roller surface. Instrumenting the conductive line to ground with a picoammeter demonstrated a discharging current correlating with charging system parameters and also time variant in accordance with Equation 4. The discharging mechanism revealed more details about toner charging characteristics, surface adhesion forces, and provided a mechanism for control of the time varying component using the toner discharge current from the applicator as a system control parameter.

Apparatus

The equipment used in the experiments was a standard single component non-magnetic toner applicator used in a high speed electron beam imaging system. Additional instrumentation was provided for sensing discharge currents and layer voltages. It was mounted on an autonomous bench test stand giving the wide range of imaging speeds from 20 to 450 feet/minute and was modified to allow for manual adjustment of controlling voltages.

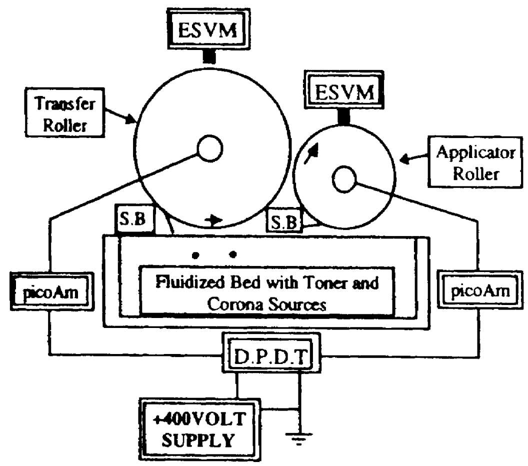

Figure 1. Schematic Representation of Single Component Non-Magnetic Toner Applicator Instrumented for Toner Discharge Experiments.

Figure 1 displays a schematic layout of the experimental apparatus. The toner, levitated by a uniformly rising column in the fluidized bed, is charged by the high voltage positive corona sources submersed in the air-toner mixture. The charged toner is transported via electric fields to the transfer roller rotating anticlockwise above the toner. A uniform layer of toner coats the roller to a thickness slightly more than a monolayer.

Two experimental modes were used during the discharge tests. The first utilized the transfer roller only. In this configuration, the transfer roller was held at ground potential while the applicator roller was biased to +400 volts. The reverse field of 2.2 V/µM holds the toner on the transfer roller as it passes through the minimum gap point in opposition to the applicator roller. Toner layer voltage and toner discharge current were monitored using a Trek 344 Electrostatic Voltmeter (ESVM) and a Keithley 485 Autoranging Picoammeter (picoAm) respectively. In the second mode of operation, the transfer roller was biased to +400 volts and the applicator roller was held at ground potential. In this configuration, the toner layer is transferred from the transfer roller to the applicator roller which is rotating in a clockwise direction. Layer voltage and toner discharge current were measure using the same instrumentation.

The rollers used in the test were coated with a polished and hardened conductive material. Most experiments were conducted with a constant roller surface speed of 100 feet/minute. Both rollers were scraped clean on every rotation by the plastic surface scraper blades (SB). Toners used in the experiments have been resistive single component non-magnetic with a mean particle size of about 12 µM. Most of the baseline tests were performed with a standard production black toner formulation. The same performance curves have been recorded, however, for the family of color toners made up with the same formulation and additives as the standard black.

Experimental

The tests performed on toner discharge and layer potential followed a similar procedure used in the standard testing procedure developed for characterizing toners used with the development system. The corona voltage was set at +7.0 kV driving twin 60 µM corona wires with a roller surface speed held at a constant 100 feet/minute (20 inches/second). Under these conditions, the normal expected M/A on the roller would be 0.7 mg/cm^2. A series of other tests were performed at speeds ranging from 50 to 350 feet/minute to gather data for the charge controller. This data is not presented herein, but would demonstrate a scaled up (or down) correlation with the baseline trials shown at 100 feet/minute.

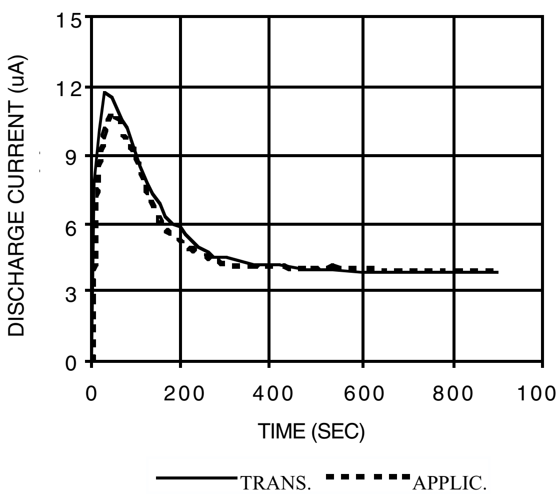

Figure 2. Toner Discharge Current Against Time as Measured on Transfer and Applicator Rollers.

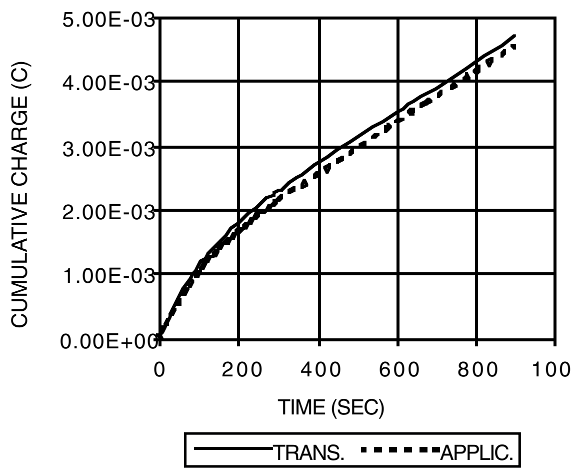

Figure 3. Cumulative Charge Lost to Transfer and Applicator Roller Against Time.

The current discharged is a rapidly rising function with a gradual exponential approach to a toner stability level. Figure 1 shows that the plots of the transfer roller and applicator roller are similar and in each case, the discharging current indicates that nearly an equal amount of charge is lost to each roller. These curves also correlate with the performance of developed image density against time and also the inverse of the normal toner stability curves plotted for the black production toner.

Numerical integration of the discharge curve gives an indication of the total amount of charge lost. Through the first 15 minutes of testing (900 seconds), total charge lost by the transfer and applicator rollers was 0.0047 Coul. and 0.0045 Coul. respectively. The difference between the two rollers (4%) could be explained by the measured transfer efficiency of the toner layer from roller to roller (95%).

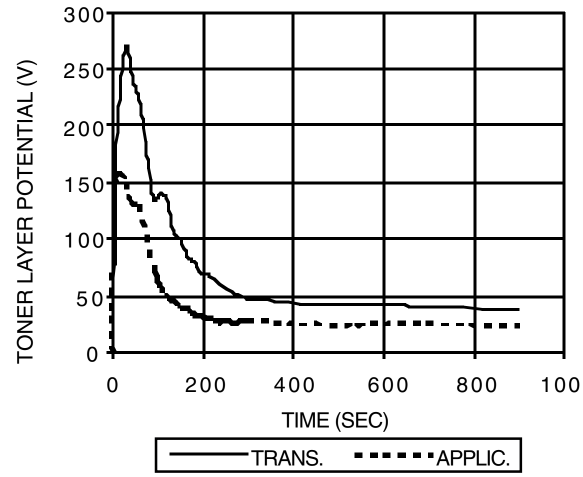

Figure 4. Toner Layer Potential on the System Rollers Against Time.

Using the non-contact electrostatic voltmeter, different time-dependent functions of toner layer voltage were measured. Overall, readings from the applicator roller were 48% lower than on the transfer roller which demonstrates a definite loss of charge. After reaching a defined stability level at the 300 second mark, the potential on the applicator roller remained 44% lower than on the transfer roller.

In an analogous format to Equation 4 which represents a time-dependent function of charge on the toner, a discharge current form of the equation can be expressed as:

$$I_{disc} = I_{field} + I_{trib} \tag{5}$$

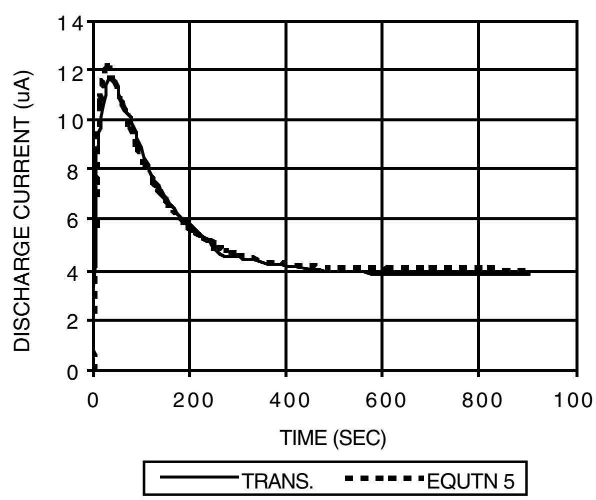

Figure 5. Theoretical vs. Experimental Curves of Discharge Current on the Transfer Roller.

Empirically determined constants were introduced into the field discharge components and triboelectric discharge components of Equation 5 and compared to the actual discharge current data collected from the transfer roller. The plot in Figure 5 shows good correlation of the actual data to a relatively simple and very crude model.

The resultant data collected on initial toner instability was utilized to develop a controlling loop based on the sensed toner discharge currents. This could be used to control either the electric field between the system rollers or the charging corona source in the fluidized bed. A comparison of open operation against controlled operation is shown in Figure 6. Measurements of the toner layer voltages on the applicator roller are plotted. Controlled operation maintains the more constant layer potential on the roller and the resultant printed density in operation is constant from the very start of imaging at t = 0.

Discussion of Results

System operation during imaging or alternate toner bench tests demonstrate direct correlation with the time varying toner discharge current. Experimental data collected for the demonstrated results was done with unused virgin toners. Toners which have been used in the charging and development operations show a lesser degree of change at system start-up dependent on the length of time of relaxation since the last use.

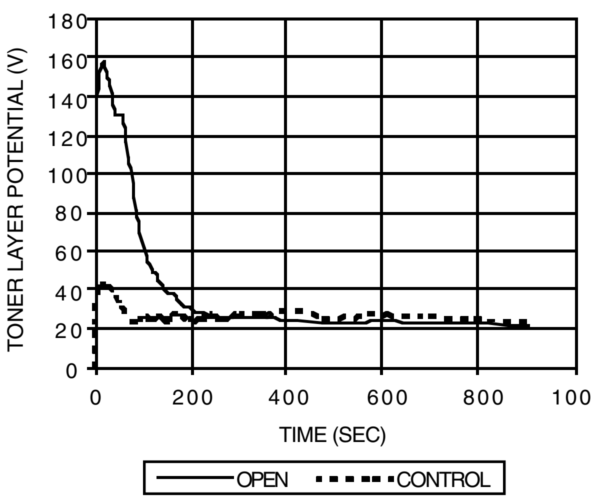

Figure 6. Demonstrated Control of Toner Layer on Applicator Roller with Discharge Current Feedback Sensing.

Discharge current and cumulative charge losses (Figure 2 and 3) show similar rates and levels on both rollers indicating that the mechanisms would be the same. The slight decline between the transfer roller and applicator roller could be explained by the measured toner transfer efficiency across the gap, the discharging effects from the first roller as measured on the second, or a degree of experimental error. These effects are not enough to explain the almost equal discharge observed on both rollers.

Measurements using the non-contact electrostatic voltmeter have been translated into toner Q/M levels.[6] This method has shown that the net Q/M on the stabilized toner layer is about +15 µC/Gm. Observing the total charge dissipated at each roller surface (Figure 3) for the final 300 seconds of the experiment, a total of 0.0011 Coulombs of charge is lost to each roller. With an initial +15 µC/Gm on a layer with an M/A of 0.7 mG/cm^2, the total charge passing through the roller systems would be 0.0035 Coulombs. Each system roller discharges about 31% of the toner charge.

The major behavioral difference between the toner performance on the successive system rollers is that of the toner layer potential (Figure 4). Lower layer potential on the applicator roller shows a definite loss of charge level. If the loss of charge from the transfer roller were uniform across the entire particle, we would expect a significantly lower discharge current on the applicator roller. Experimental results did not show this. This would lead to the conclusion that the discharge mechanism is localized to the area on the particle in closest proximity to the conductive roller surface. This discharged patch on the particle has two effects. The particle would now have an uneven or polarized charge distribution. In the electric field between the system rollers, particles would be transported in a similar orientation and land on the applicator roller with the charged side down. This would explain the consistency of toner discharge current from each roller even though 30% of the charge is already lost to the first roller. With the discharged side sitting outward on the applicator roller, the observed loss in layer potential is a second effect of the polarized particles. The observed layer voltage decreased by 44% to the applicator roller, which is approximately consistent with the observed charge loss. The second major effect of the discharged patch would be a reduced surface adhesion force caused by a combination of reduced charge level and uneven distribution of charge on the particle. Adhesion forces could be reduced as much as 50 to 75% on a typical 12 µM spherical particle which has lost 30% of its net charge.

Use of the discharge current to monitor charge level on the toner has provided a successful method to control toner parameters such as Q/M, Q/A, and M/A by adjusting system drivers to achieve desired responses. In developing the control method, a means for measuring the field charging and triboelectric charging properties of toner has provided valuable information in further understanding this process for monocomponent resistive toner development.

Acknowledgments

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