Analysis of the Tribocharging Mechanism and the Surface Properties of a Development Roller in an Electrophotographic Toner Development System

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Abstract

In previous work, we observed that current flows through each system part (i.e. development roller, blade, and supply roller) in normal operation during roller rotation in a mono-component development system. Measurement of these currents was shown to be useful for determining toner charging and charge transfer mechanisms. A theoretical analysis of the process is presented and by comparing this with the experimental data, it is suggested that an effective bias is generated between the doctor blade and the development roller surface due to the toner charging. By measuring the surface potential on the development roller as it was rotated, charge trapping at the development roller surface was experimentally observed. This trapped charge was released by contacting with the supply roller. It was found that the surface characteristics of the development roller considerably affected the current and the charge retention of the surface. This is shown to result in a "residual voltage" that is related to the effective bias controlling the current flow.

Introduction

Previously we discussed the toner charging and the toner transport mechanism by using a current measurement technique.[1,2] Hosoya et al. also observed current through the doctor blade when the development roller is rotating with attached toner on its surface.[3] Field reported current generation at the development roller when it began rotation.[4] However these phenomena are complex and the reason for the current generation or the relationship to the toner charging was not clear. In a previous paper, the authors proposed a theoretical model of the current generation mechanism between the doctor blade and the development roller.[1] This model shows that the current is highly dependent upon the toner charge density and the roller rotation rate. Also it was observed that the current is limited by a reverse effective bias that is generated at the development roller surface. In this paper, we focus on the current generation mechanism when the toner passes the doctor blade or the supply roller. For this purpose, the toner charge, the toner mass on the development roller, the surface properties of the roller and the process currents in a development system were measured using a modified cartridge with the supply roller either present or removed. Also the surface potential at the development roller surface was measured in order to directly observe the generated effective bias and to determine its relation to the "residual voltage". The relationship between the roller features and the current generation are discussed according to the development system conditions.

Experimental

Development Rollers

Development rollers consisting of an elastic polyurethane base coated with a thin resin layer were prepared for this study. The fundamental characteristics of the rollers are given in Table 1. Rollers NC10 to NC30 can be characterized as having an insulating surface layer and are arranged in the order of increasing thickness of the surface layer. Rollers CB10 to CBL6 can be characterized as having a semi-conductive surface layer. Here the electrical resistivity of the surface layer was changed by varying the concentration or grade of carbon black (CB). The roller surface was charged using a corona charger (supplying DC 8 kV), and the surface voltage relaxation was measured as function of time using the surface potential meter. In this paper we define the value of the surface potential at 0.35s, (i.e. time for one rotation of the DR at rated speed), after the corona charging as the "residual voltage".[1,2] This parameter shows the charge holding ability of the roller surface. The diameter and length of the roller are 20 mm and 345 mm, respectively and the diameter of the roller shaft is 12 mm.

Table 1: Fundamental Characteristics of the Development Rollers

	Surface layer		Log roller resistance applied voltage : 100V (Ω)	Surface roughness Rz (μm)	Residual voltage (V)
	Resin concentration	CB contents			
NC10	10%	0	7.80	6.10	13
NC15	15%	0	7.77	3.73	86
NC20	20%	0	8.15	1.27	449
NC25	25%	0	8.35	1.03	762
NC30	30%	0	9.49	1.02	873
CB10	20%	10%	7.76	1.19	156
CB20	20%	20%	7.83	1.11	52
CB30	20%	30%	7.39	1.21	17
CBL6	20%	L6 30%	6.03	2.35	2

Toner, Development System and Roller Rotating Machine

A non-magnetic, mono-component, negative charging type toner was used in this study. It was pulverized toner and the mean particle size based on weight was 7.1 µm. We used a commercial toner cartridge having a stainless steel doctor blade and a polyurethane foam supply roller. We modified this system in two ways. First a roller driving system was adapted to allow the development roller to rotate without contacting the OPC drum. Secondly a development system without the supply roller was also used. In this case toner was attached on the roller surface by using the conventional system, and then the development roller assembly was carefully removed. And it was mounted in an identical unit without the supply roller. In this system, the same toner remained on the development roller as the roller rotated.

Measurement of Toner Charge

A suction type Faraday cage was used to measure the toner charge and its mass. Toner on the surface of development roller was collected in the Faraday cage through a shielded sampling tube. Toner mass/area ratio (m/a) was calculated from the toner mass collected in the Faraday cage and area of the development roller from where toner was removed.

Measurements of Current at Each Part of the Development Assembly

Three electrometers were connected between each development unit part (blade, development roller and supply roller) and ground. The development process currents were monitored by the three electrometers and the current data were transferred to a personal computer through a GP-IB bus. The roller was rotated for 3 seconds and the current was monitored during the process from start to the stop of rotation. The value of current was determined from the average over 3 seconds from the start to stop points. The rotation rate of the development roller was 250 rpm and was varied here from 50 to 250 rpm.

Measurements of Surface Potential

The surface voltage meter was set at 2 mm from the development roller surface. The instantaneous surface potential of the toner on the development roller surface was monitored by an oscilloscope and measured simultaneously with the current measurements.

Results

Toner Charging Characteristics

The toner charging characteristics for each roller in the system with and without the supply rollers are shown in Fig. 1. The magnitude of the toner charge/area (q/a) remained approximately constant for the rollers NC10 to NC30 decreased for rollers CB10 to CBL6 with an increase in the roller surface conductivity. Although there was some larger experimental variation in the system without the supply roller, the results were almost the same with and without the supply roller present. The relationship between q/a and rotation rate was measured in both of the systems. It was observed that the toner charge (q/a) level was almost independent of the roller rotation rate.

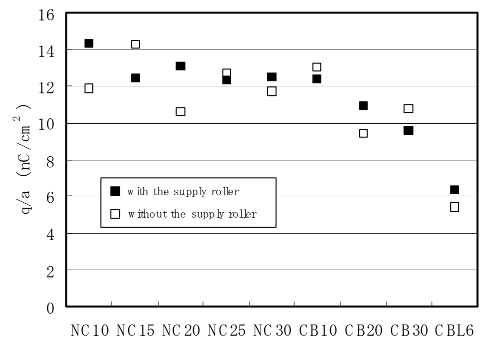

Figure 1. Toner charge (q/a) for each roller with and without supply roller at 250 rpm.

Current Measurements

Each part of the development unit was connected through an electrometer to ground and the currents at each part (Id: through development roller, Ib: through blade, Is: through supply roller, It: total current) were measured in the development process. Figure 2 shows some typical results of the current measurements. Note that the current flow was observed in each part only when the roller was rotating. The total current, which is the algebraic sum of each current, is approximately zero. This means that no significant current leakage through other parts occurred in this development system. As we reported in the previous reports, the process currents were also observed in the system without the supply roller.[2] In this case the absolute values of blade current and development roller current at each point are equal except for direction and the total current, which is the algebraic sum of each current, is also approximately zero. These process currents also depend on the roller rotation rate. It was observed that the magnitude of the current increased with an increase of the roller rotation rate.

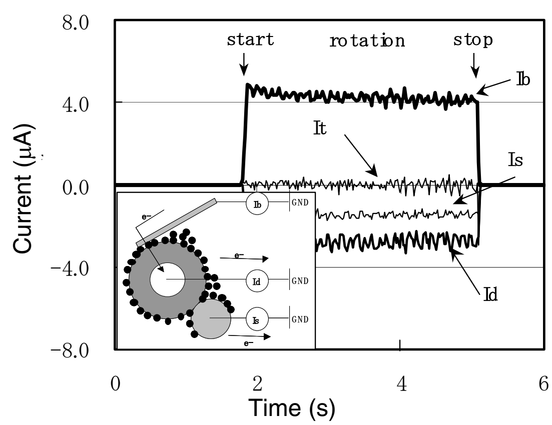

Figure 2. Current through each part for NC20 roller with supply roller present at 250 rpm. (arrow indicates electron flow).

Surface Potential Measurements

The surface potential for the toner layer on the development roller surface was measured at rotation rates varying from 50 to 250 rpm. In all cases it was observed that the surface potential increased in magnitude with an increase in the rotation rate of the roller and decreased in magnitude with an increase in the surface layer conductivity. Similar trends were observed in the system without the supply roller.

Discussion

Theory of the Blade Current Generation in the System without the Supply Roller

First, we focus on the blade current and discuss the current generation mechanism without the influence of the supply roller. We have already proposed a theory of the blade current generation.[1] The general model includes the case in which the doctor blade is in a biased condition. The schematic figure of this model is shown in Fig. 3. In this model, the surface charge density σ is described by Eq. (1) And the system current is described as Eq. (2).

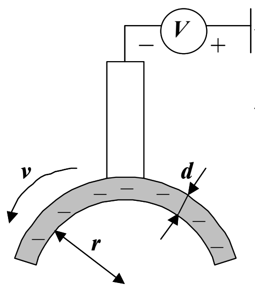

Figure 3. Relationship between development roller current (Id) and rotation rate with supply roller present as a function of rate of rotation.

$$\sigma = \left[(V - IR)\frac{\kappa \varepsilon_0}{d} + q/a \right] \tag{1}$$

$$I = \left[(V - IR)\frac{\kappa \varepsilon_0}{d} + q/a \right] L v \tag{2}$$

Equation (2) may be solved explicitly for current $\boldsymbol{I}$ and rewritten as Eq. (3). This equation is the basic model of current generation based on the toner charging, doctor blade bias voltage and potential drop due to the finite roller resistance.

$$I = \frac{V \frac{\kappa \varepsilon_0}{d} L v + (q/a) L v}{1 + R \frac{\kappa \varepsilon_0}{d} L v} \tag{3}$$

In this current study, no doctor blade bias voltage was applied ($\boldsymbol{V}$=0) thus Eq. (3) becomes Eq. (4) where the current is entirely caused by the movement of the charged toner past the doctor blade.

$$I = \frac{(q/a) L v}{1 + R \frac{\kappa \varepsilon_0}{d} L v} \tag{4}$$

Figure 4 shows the comparison of experimental data of the roller NC20 and theoretical curves of Eqs. (3) and (4). Note that Eq. (4) seriously over-predicts the current flow but Eq. (3) shows good agreement when an appropriate value of bias "V" was determined from curve fitting which in this case it was found to be 150 V. For all the rollers tested the experimental data was similarly found to be smaller than the theoretical prediction of Eq. (4). Thus it is suggested that an effective bias is generated in the experimental case. An equivalent effective bias was obtained for each roller case by curve fitting.

Discussion of the Mechanism of Surface Potential Generation

It is clear that the surface potential of the development roller is determined by the sum of the toner charge density, any external voltage applied to the development roller and the presence of any residual voltage on the surface due to charge retention. In this study, no external bias voltage was used and the toner charge was approximately constant regardless of the rotation rate of the roller. Thus it is assumed that there is another factor for affecting the surface potential in addition to the toner charge density or external bias voltage. As described above we consider that this mechanism affecting the surface potential is due to the effective bias that is generated when the current is flowing. By using the experimentally determined value of effective bias for each roller, the relationship between the surface potential and q/a multiplied by the effective bias is shown in Fig. 5. The physical meaning of the product q/a and effective bias can be considered to be that of a "surface energy" and should be related to the surface potential. Here it can be seen that the results are scattered around a broad trend line confirming the presence of the effective bias at the development roller surface. As shown in Fig. 5, it is noticed that this trend line does not pass through the zero origin point. This result indicates that the effective bias still remains on the surface even in the case if the toner has no charge (q/a=0). This implies the presence of some trapped charge on the surface of the roller.

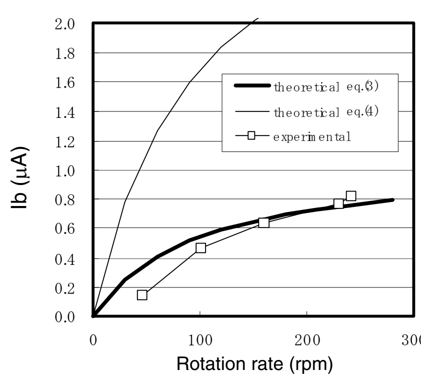

Figure 4. Schematic diagram of current flow through the doctor blade and development roller.

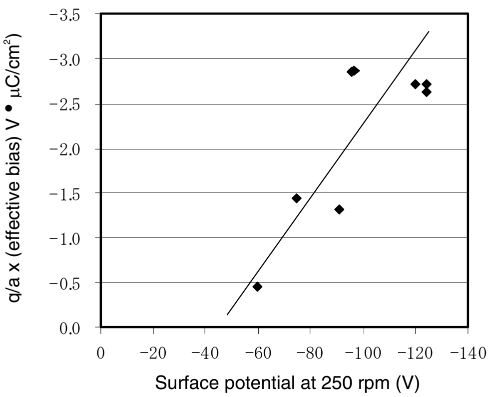

Figure 5. Comparison of theoretical curve with experimental data for NC20 roller.

The tendency for the roller to hold charge is related to its effective capacitance and results in the measured residual voltage that is shown in Table 1. Thus it can be assumed that the surface potential is related to the residual voltage and toner charge density. To corroborate this assumption, the values of q/a multiplied by the residual voltage are plotted as a function of surface potential in Fig. 6 for all the rollers tested with the supply roller present for a rotation rate of 250 rpm. A clear relationship is observed confirming this interpretation.

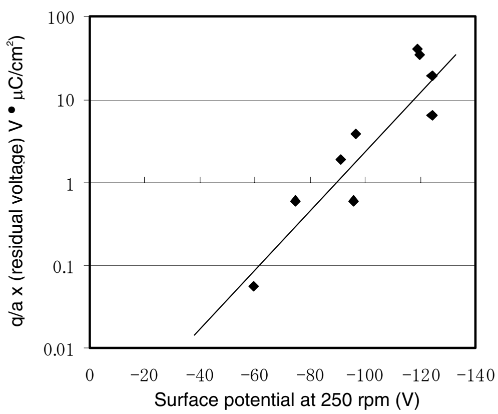

Figure 6. Relationship between (q/a x "effective bias") and surface potential.

Discussion of the Influence of the Supply Roller for Surface Potential

To clarify the influence of the supply roller on the surface potential, the surface potentials were measured under various conditions. First, the roller was rotated at 250 rpm and the surface potential was measured. Then these measurements were repeated at the rotation rate of 50 rpm. Figure 7 shows an example of the results of surface potential measurements in the system at 50 rpm with the supply roller present for the development roller NC20. The surface potential was initially at a level of –123 V when the roller was rotated at 250 rpm. The surface potential then rapidly decayed to a value of –85V soon after the roller started rotating at 50 rpm. The same experiment was done for the system without the supply roller. In this case, the initial surface potential was –105V, and no decay in surface potential was observed when the rotation rate was decreased to 50 rpm. These results suggest that the supply roller cancels the surface charge of the development roller, which is determined by both the toner charge and the charge trapped on the development roller surface. This phenomenon is observed as a current flowing through the supply roller. Figure 8 shows the relationship between the supply roller current and the surface potential in the system with the supply roller present. The data correlate well around the trend line confirming the interpretation that the supply roller cancels the surface charge on the development roller.

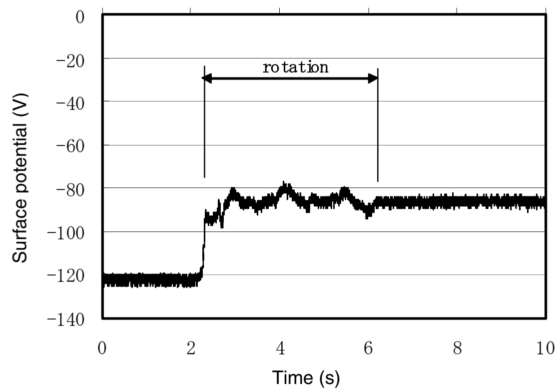

Figure 7. Relationship between (q/a x "residual voltage") and surface potential.

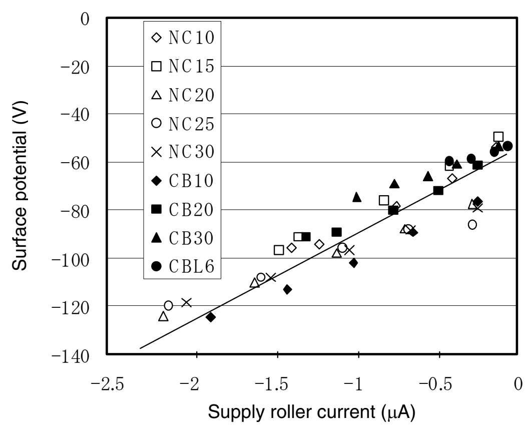

Figure 8. Change in surface potential associated with rotation aof the roller NC20 in the system with the supply roller.

Conclusion

The dynamics of mono-component non-magnetic toner charging in the development cartridge is discussed by using a current measurement technique. The proposed general current flow theory considers the toner charge layer as it moves past a doctor blade in contact with the roller having finite resistance. General agreement between the experimental and theoretical results has been shown when it is assumed that there is charge trapping at the roller surface. This charge trapping behaves as an effective bias in the system. The surface potential at the toner surface on the development roller was also measured, and the existence of this effective bias was experimentally confirmed. It is proposed that the surface potential is important in affecting the magnitude of the current flow and is determined by two parameters; the toner charge density and the charge trapped at the development roller surface. This results in an effective bias in the system that acts to restrain the blade current flow. The supply roller cancels the surface charge on the development roller and this charge cancellation is observed as a current.

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Author Biography

Koji Takagi received the B. Eng. and M. Eng. degrees from Yokohama National University Japan in 1985, 1987. He joined Bridgestone Corporation in 1987 and is working for the R&D division. In 2005, he received the Ph.D. degree from Ibaraki University.