Analysis of the Surface Properties of a Development Roller for Mono-Component Toner Charging by Using a Current Measurement Technique

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Abstract

In the mono-component non-magnetic toner system, optimum toner charging and mass transfer are important factors to produce fine images with high quality. In previous work, we confirmed that a current flows through each system part (i.e. development roller, blade, and supply roller) during the roller rotation with toner attached on its surface. In this paper, we discuss the possible mechanism of generation of these currents in the development system. Development rollers having various surface properties were prepared for this study. It was found that the surface characteristics of the development roller considerably affected the value of the current. In particular the rate of charge decay of the roller surface strongly affected the current and also the toner charging. From these results, we propose a possible mechanism for this current generation.

Introduction

Proper toner charging and mass transport are important factors needed to produce fine and high quality images in the electrophotographic development system. In previous studies Castle and Schein proposed a model of contact charging between insulators, and showed that most of published experimental results were fitted to their model.[1] R. Nash, et al. studied the dynamics of toner charging by observing the time-dependence of toner charge.[2] Yamaguchi et al. reported toner charging behavior in a non-magnetic toner developing system, and discussed the influence of toner charge distribution on the development performance.[3] However, there are few reports that focus on the toner charging mechanism in the development system. In particular the dynamics of toner charging in the development system is very complicated and it is hard to clarify its mechanism. Previously we have discussed the toner charging and the toner transport mechanism by using a current measurement technique.[4,5] Hosoya et al. observed current through the doctor blade when the development roller is rotating with attached toner on its surface.[6] Field reported current generation at the development roller when it began rotating.[7] We found that a microscopic current is observed through each part of the development system when the toner is charged or transported. We proposed an assumption that the toner charging is mainly caused by the toner in contact with the roller surface passing by the blade. Also it is realized that the surface properties of development rollers are very important factors to determine the toner charging.

In this paper, we focus on the toner charging mechanism as the toner passes the blade and the current generation mechanism. For this purpose, the toner charge, toner mass on the development roller, surface properties of the roller and the process currents in a development system were measured. We will discuss the relationship between the roller and toner properties, since the experimental results suggest an important role of the development roller surface. Also a current generation mechanism in the development system is discussed.

Experimental

(1) 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. The resin which was used for the surface layer was alkyd-melamine based resin, which was very insulating having a resistivity higher than 10^{14} Ωcm. Rollers NC10 to NC30 are arranged in order of the thickness of the surface layer. The resin concentrations described in Table 1 are the fraction of resin in the solvent before coating, which are proportional to the thickness of the surface layer. It is not easy to measure the thickness of the surface layer directly, but it is approximately 5 μm at 10% concentration, 10 μm at 20% and 20 μm at 30%. The roller resistance was measured by applying 100V bias between the roller shaft and metal plate that was contacted with the roller surface.

Table 1. Fundamental Characteristics of Development Rollers.

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

The roller resistance increases and surface roughness decreases with an increase in surface layer thickness. For rollers CB10 to CBL6 the electrical resistivity of the surface layer was changed by varying the concentration or grade of carbon black (CB). The carbon blacks used in this study were Printex 35 (low structure, larger particle, furnace black) and L6 (high structure, high conductivity grade) (both from Degussa Co.). Carbon L6 produces a more highly conductive surface layer than Printex35. The roller resistance decreases with an increase in the CB content in the surface layer. The diameter and length of the roller are 20 mm and 345 mm, respectively. The diameter of the roller shaft is 12 mm.

(2) Measurements of Charge Relaxation and Residual Voltage

The charge relaxation time of the bare development roller surface was measured using a surface potential meter (QEA Inc.: CRT-2000).[8] The roller surface was charged using a corona charger (supplying DC 8kV), and the surface voltage relaxation was measured as function of time using the surface potential meter.

(3) Machine and Toner

We used a commercial laser beam printer toner cartridge for this study. Negative charge type toner was used having a mean particle size (d0.5) based on weight of 7.13 mm. In this machine the doctor blade was made of stainless steel, and the supply roller was made of polyurethane foam. 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 used in this study. In this case toner was attached on the roller surface by using the conventional system, and then the development roller was carefully removed from the development system. The excess of remaining toner between the supply roller and blade was removed by light vibration. In the system without the supply roller, the same toner remained on the development roller as the roller was rotated.

(4) Measurements 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 the vacuum pipe. The OPC drum was removed from the machine for toner charge measurements. 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.

(5) Measurements of Current at Each Part in Development Process

Two electrometers were connected between each development unit part (blade, development roller) and ground. The development process currents were monitored by the two 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 all through the process from start to stop rotation. The value of current was determined from the average over 3 seconds from the start to stop point. The rate of rotation of the development roller was varied from 50 to 250 rpm.

Results

(1) Charge Relaxation – Residual Voltage of Development Roller Surface

Examples of charge relaxation curves for the NC15 roller (15% resin content, zero CB content) and CB20 roller (20% resin content, 20% CB) are shown in Fig. 1. It can be seen that the surface voltage decayed faster in the CB20 roller than in NC15 roller. The roller normally rotates at 171 rpm in the development roller system. Thus it takes around 0.35 s for one rotation. We defined the value of the surface potential at 0.35 s after the corona charging as the “residual voltage” in this paper. The results for all the rollers are shown in Fig. 2.

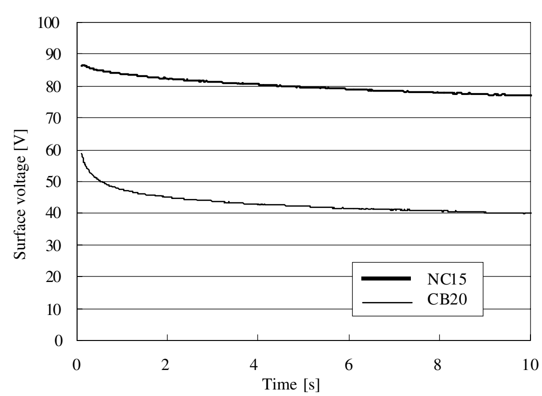

Figure 1. Examples of charge relaxation curves. (NC15 and CB20 rollers).

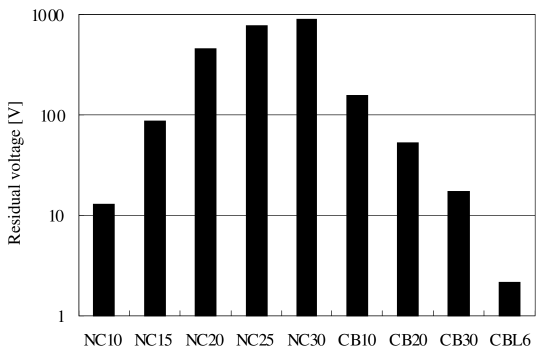

Figure 2. Residual voltage in each roller.

(2) Current Measurements

The development roller and the blade were connected to ground and the currents at each part (Id: through development roller, Ib: through blade, It = Ib + Id : total current) were measured in the system without the supply roller. In this case, the toner was emptied from the cartridge box so that no toner exchange on the development roller surface occurred. Figure 3 shows the results of the current measurements for the NC10 roller in this system when rotated at a speed of 250 rpm. The current flow was observed and the direction of the electron flow is indicated in Fig. 3. 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 approximately zero.

In order to clarify the cause of these currents, the toner was emptied completely from the cartridge and development roller surface and the currents were measured in the same way. No current was observed in this case. Therefore, it can be concluded that the currents observed originate from the tribo-charging of the toner. Figure 4 shows the results of the current measurements for the NC30 roller when rotated at a speed of 250 rpm. Compared with Fig. 3, the current decay is observed in this case. For all the measurements the current magnitude was found to be proportional to the speed of rotation of the development roller.

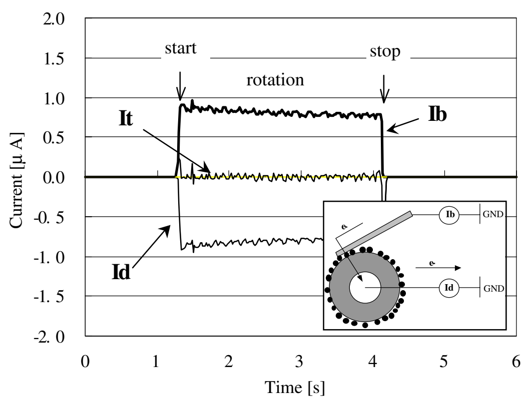

Figure 3. Currents through each part for NC10 roller.

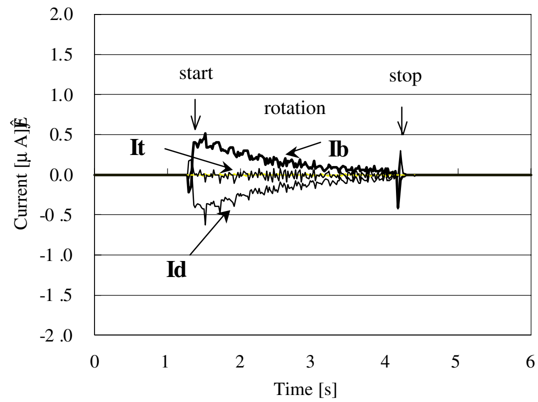

Figure 4. Currents through each part for NC30 roller.

(3) Toner Charging in the System Without Supply Roller

The toner charging characteristics for each roller are shown in Fig. 5 when rotated at a speed of 250 rpm. The relationship between q/a and rotation rate was measured in the system with the supply roller. It was observed that the toner charge (q/a) level was almost independent of the roller rotation rate. The toner charge/area (q/a) decreased with an increase in surface conductivity, as shown with CB10 to CBL6.

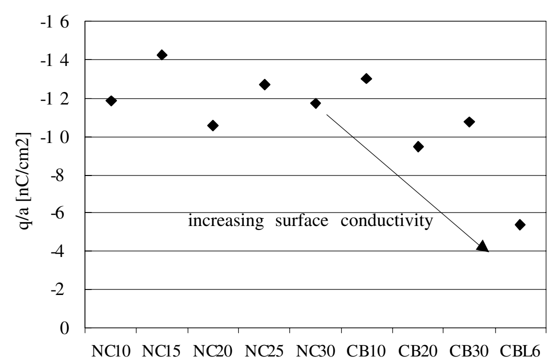

Figure 5. Toner charge (q/a) for each roller without supply roller system.

Discussion

It appears that the observed current originates from the dynamic nature of the toner charging process. We suggest here a current generation mechanism by describing the toner charge layer as it moves past a doctor blade in contact with the roller having finite resistance. 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. 6. In this model, the surface charge density σ is described by the following equation.

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

where V is the doctor blade bias voltage, I is the current, κ is the apparent relative permittivity of toner layer ($\varepsilon = \kappa\,\varepsilon_0$, κ=1.1). In the development system, the electric field is formed between doctor blade and development roller surface. Thus the distance of d is the thickness of toner layer ($d = 2\times10^5$ m). The system current is described as Eq. (2).

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

where L is the roller length (L=0.34 m) and v is the linear velocity of the roller. Equation (2) may be solved explicitly for current I and rewritten as Eq. (3).

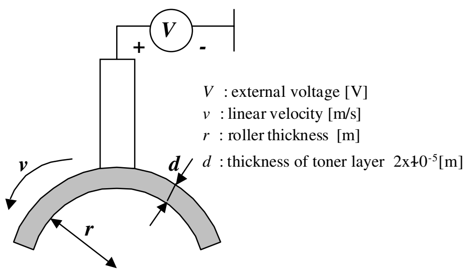

Figure 6. Schematic drawing of current flow.

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

This equation is the basic model of current generation based on the toner charging, doctor blade bias voltage and potential drop by the finite roller resistance. Note the current is zero when the roller is not rotating (v = 0). Figure 7 shows the effect of varying the value of external bias V for a fixed value of $q/a = -15$ nC/cm^2 and $R = 10^7\Omega$. These curves demonstrate that the current decreases as external bias increases.

In this paper, no doctor blade bias voltage was applied (V=0). Thus Eq. (3) becomes Eq. (4).

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

Eq. (4), shows that for the case of the roller resistance R=0, the current can be explained as being caused by the movement of the charged toner past the doctor blade. Note that for the case of uncharged toner i.e. q/a = 0, there is no current flow. Figure 8 shows the effect of varying the value of toner charge q/a for a fixed value of $R = 10^7\Omega$. The value of current is directly proportional to the toner charge. Figure 9 shows the effect of varying the value of R for a fixed value of $q/a = -15$ nC/cm^2. These curves demonstrate that the current decreases as R increases and the dependency becomes non linear with the speed of rotation as R increases.

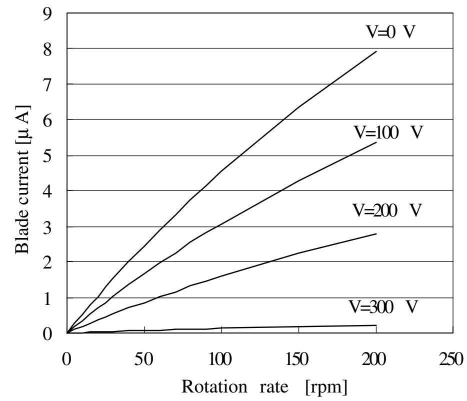

Figure 7. Simulation results of the effect of external bias V on the blade current.

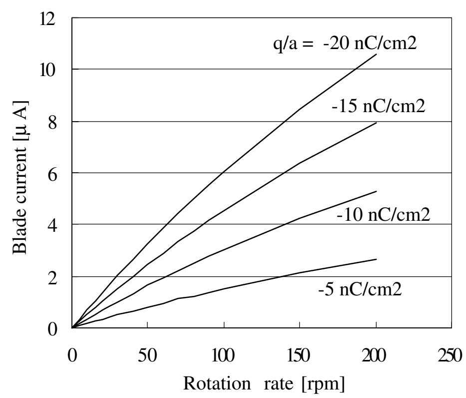

Figure 8. Simulation results of the effect of toner charge q/a on the blade current.

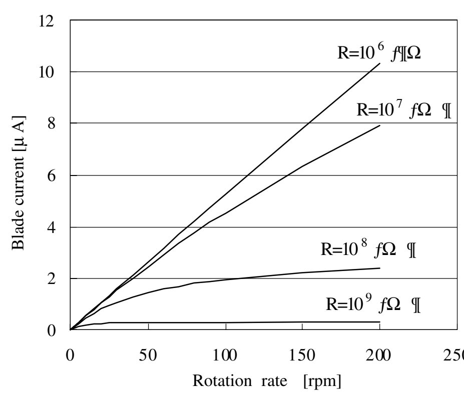

Figure 9. Simulation results of the effect of roller resistance R on the blade current.

Figures 10 and 11 show the comparison of experimental data of the roller NC20, CB20 and theoretical curves of Eq. (3) and (4). For the theoretical curves of Eq.

(3), the appropriate offset bias "V" was determined from curve fitting. The offset bias for the NC20 roller was 150 V and CB20 roller was 80 V. Compared with the theoretical curves of Eq. (4) and the experimental data, the experimental data are smaller than the theoretical curves. In the case of theoretical curves of Eq. (3), the theory and experiment results are much closer than the Eq. (4) case.

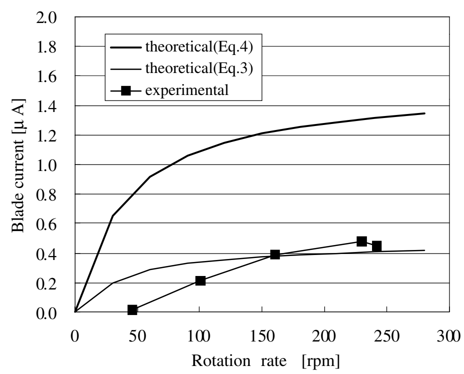

Figure 10. Comparison of theoretical curve with experimental data for NC20 roller.

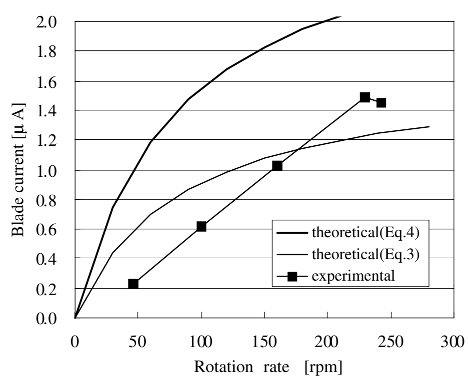

Figure 11. Comparison of theoretical curve with experimental data for CB20 roller.

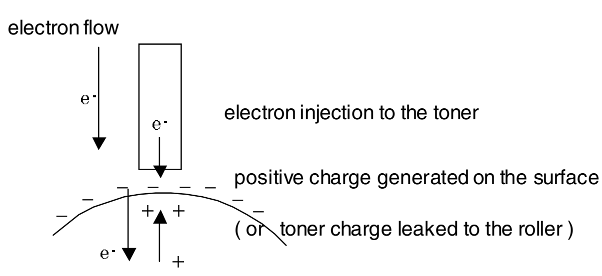

Figure 12. A model of charge flow.

Thus it is suggested that an effective bias (equivalent to the offset bias in Eq.(3)) is generated in the experimental case. The schematic figure of current flow is shown in Fig. 12.

A counter positive charge is generated on the development roller surface in contact with the negative toner charge. This counter charge remains at the roller surface, and it works as an effective bias described as "V" in Eq. (3). As shown in Fig. 7, the current decreases with an increase of external bias. Thus it is suggested that the discrepancy between the theory and experiment shown in Eg. (4) can be explained by considering the effective bias that is generated at the roller surface. This generated effective bias is related to the charge holding ability at the roller surface, as measured by the "residual voltage". As shown in Fig. 4, the current decay is observed for the rollers demonstrating high residual voltage. These results can be explained by this effective bias generation mechanism. After several roller rotations, the positive charge is generated and saturated at the roller surface. Thus it is suggested that the positive effective bias increases and the current decay observed as shown in Fig.4. Figure 13 shows the relationship between the residual voltage and blade current (Ib) for a fixed value of rotation speed at 250 rpm. A clear relationship is observed in this case. It can be seen that the observed current has a strong dependency on the residual voltage, a value that is related to the effective bias. The two isolated points are for NC10 and CBL6 rollers. The surface roughness of the NC10 roller is very large and it has large toner transport. The surface conductivity of CBL6 roller is very high and contains a lot of carbon black on the roller surface. The reasons for the discrepancies are not clear at this point, but we thought these two rollers contain different toner charging mechanisms and current generation.

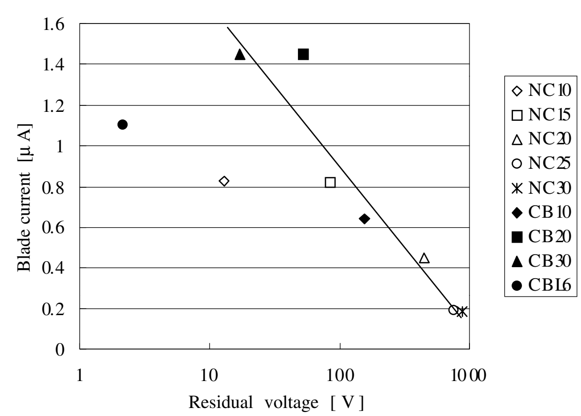

Figure 13. Relationship between residual voltage and blade current (lb). (250 rpm).

Another difference between the theoretical and experimental curves is the linearity. The experimental curves are steeper than the theoretical curves. As already shown in the simulation results in Fig. 9, the influence of the finite roller resistance is considered to be an important factor. One of the reasons for this discrepancy is thought to be due to the assumed value of the effective roller resistance. First, the roller resistance has certain dependence of applied voltage. The roller resistance increases for the case of smaller applied voltage.[9] In this paper, the roller resistance was measured using an applied voltage of 100V. Thus the actual effective value may be smaller. In addition the effective roller resistance may also be dependent upon the rotation rate.

Conclusion

The dynamics of mono-component non-magnetic toner charging in the development cartridge is discussed by using a current measurement technique. The system used for this study was a commercial unit modified so that the OPC and supply roller were removed. It was confirmed that current flows through the development roller to the blade during the roller rotation with toner attached on its surface. The general current flow theory is proposed by describing the toner charge layer as it moves past a doctor blade in contact with the roller having finite resistance. Although there are some discrepancies, general agreement between the experimental and theoretical results has been shown when it is assumed that the positive charge generation at the roller surface behaves as an effective bias in the system. It is shown that this effective bias is related to the value of "residual voltage" retained by a roller. A second reason for the difference between the experiments and the theory is believed to be due to the uncertainty in accu rately measuring the resistance of the roller in operation.

Acknowledgement

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Biography

Koji Takagi received the B. Eng. and M. Eng. degrees from Yokohama National University Japan in 1985, 1987. In 1987 he joined Bridgestone Corporation and is working for the R&D division. He is now studying at the Department of Electrical Engineering at Ibaraki University.