The Relationship Between Toner Charging and Properties of the Development Roller for Minimizing Degradation of Imaging Density

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Optimum toner charging and mass transfer are important factors to produce fine images with high quality in electrophotography. Also the uniformity of the image is one of the most important properties to produce high quality printing. The charging mechanism of toners and the mechanism of toner development in the electrophotographic monocomponent laser beam printer system was studied in this article. Development rollers with various surface properties were prepared. The dynamics of toner charging were investigated by using a current measurement technique. A current was observed to flow through each system part, i.e., development roller, blade, and supply roller, during the roller rotation with toner attached on its surface. Currents and toner charge to mass ratio and the uniformity of printing image were measured for each roller. It was found that the current had a strong relationship to the roller surface properties. It was also shown that the relationship between toner charge and roller surface properties is related to the uniformity of printing image. Finally the mechanism of toner development is discussed, and the design of a high quality development roller is proposed.

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Introduction

Proper toner charging and mass transport are important factors needed to produce fine and high quality images in the electrophotographic development system. Also the uniformity of the image is another important factor for high quality printing. It is observed occasionally that the imaging density (ID) decreases continuously along the paper feed direction as shown qualitatively in Fig. 1. This phenomenon is also known as ghosting and the mechanism has been investigated, considering various causes due to the OPC materials, development rollers, supply rollers, etc. Most reports suggest this phenomenon may be attributable to the fact that the toner developing conditions are slightly different between the front and back of the printing image. In this article we address the influence of the development roller properties on this ghosting phenomenon.

During development at the front of the image, the development roller and the toner condition are stable because the roller has rotated several times before the development is started. On the other hand, toner development, toner supply and toner charging are taking place simultaneously during development at the back of the image. This is considered as an unstable condition. In order to provide a uniformly printed image, it is important to analyze the toner developing mechanism under this unstable condition.

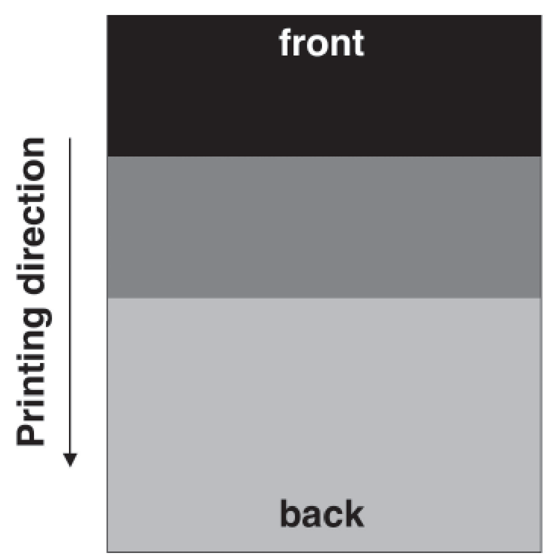

Figure 1. Schematic drawing of non-uniformity print image.

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TABLE I. Fundamental Charactristics of Rollers Used in this Study

	base layer		surface layer		log roller resistance [Ω]	surface
	resin concentration	CB contents	resin concentration	CB content	(applied voltage) 100V	roughness Rz [μm]
N1			10%	—	7.4	10.1
N2	not available		15%	—	7.4	8.2
N3			20%	—	7.5	5.4
N4			25%	—	8.0	1.4
N5			30%	—	over range	1.0
C1			20%	10%	7.5	4.5
C1	not available		20%	20%	7.0	3.3
C1			20%	30%	6.2	4.2
T1	20%	20%	10%	—	6.6	5.5
T2	20%	20%	15%	—	6.6	5.8
T3	20%	20%	20%	—	6.7	4.5
T4	20%	20%	25%	—	6.5	1.7
T5	20%	20%	30%	—	6.9	1.1

In a previous study 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] 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 developing system, and discussed the influence of toner charge distribution on the development performance.[3] Many other workers have also studied these effects. However, there are few reports which focus on the toner charging mechanism in the development system. Based on studies of printed images, Castle and Adamick discussed a numerical approach for toner development to the solid imaging area.[4] Takaya, et al. reported the mechanism of ghost formation in terms of the diameter of the toner particle.[5] Aoki, et al. reported that contacting a biased-brush to the development roller surface improved uniformity of printing.[6] However, there are also few reports which focus on the development roller properties for the uniformity of printing images.

The purpose of this article is to clarify the mechanism of the development process in the electrophotographic system. Especially we focus on the influence of the development roller surface on the image uniformity. For that purpose, toner charge, toner mass on the development roller, surface properties of the roller and the process currents in a development system were measured as well as the image quality for the development roller surface with various properties. We will discuss the relationship between the roller and toner properties because the experimental results suggest an important role for the development roller surface as well as the toner movement from the development roller surface to the organic photoconductor (OPC) drum.

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 I. Rollers N1 to N5 are insulated surface layered rollers, rollers C1 to C3 are conductive surface layered rollers, and rollers T1 to T5 are two layered rollers which have conductive base layers over coated with an insulating layer. Each roller is arranged in the order of the thickness of the coated layer. The resin concentrations described in Table I are the fraction of resin in the solvent before coating, which becomes proportional to the thickness of the surface layer. It is not easy to measure the thickness directly, but it is approximately 5 μm at 10% of concentration, 10 μm at 20% and 20 μm at 30%. The insulating layer had a resistivity higher than 10^{14} Ωcm. The conductivity of the conductive layer was controlled by changing the concentration of carbon black (CB). The carbon black used in this study was Printex™ 35 (furnace black from Degussa Co.). The roller resistance was measured by applying a 100 V bias voltage between a conductive drum electrode and the development roller. The resistance was measured during rotation, and the average data are shown in Table I. The diameter and length of the roller are 20 mm and 300 mm, respectively. The diameter of roller shaft is 12 mm.

Toners

A non-magnetic, monocomponent, negative charging type toner was used. It was polymerized, spherical toner, and the weight average particle diameter was 6.7 μm.

Development System and Roller Rotating Machine

A commercial laser beam printer (LBP) and toner cartridge were used for this study. The doctor blade and the supply roller of the machine were made of stainless steel and polyurethane foam, respectively. An external bias voltage was applied on each part of the toner cartridge, –300 V for the blade and development roller, and –580 V for the supply roller. A special roller driving system was used to allow the development roller to rotate without contacting the organic photoconductor (OPC) drum.

Measurements of Charge Relaxation and Residual Voltage

The charge relaxation on the bare development roller surface was observed using a surface potential meter (QEA Inc.: CRT-2000), and the time constant for charge relaxation was obtained.[7] In these tests the roller surface was initially charged by a corona charger supplying 8 kV DC, and the surface voltage relaxation was measured by the surface potential meter as a function of time.

Measurement of Toner Charge

A suction type Faraday cage was used to measure the toner charge and its mass (q/m) on the development roller surface. Toner on the surface of the development roller was collected in the Faraday cage through a

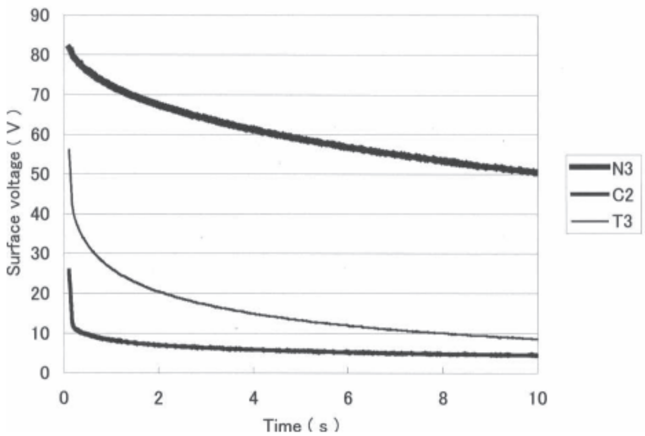

Figure 2. Examples of charge relaxation curves (rollers N3, C2 and T3).

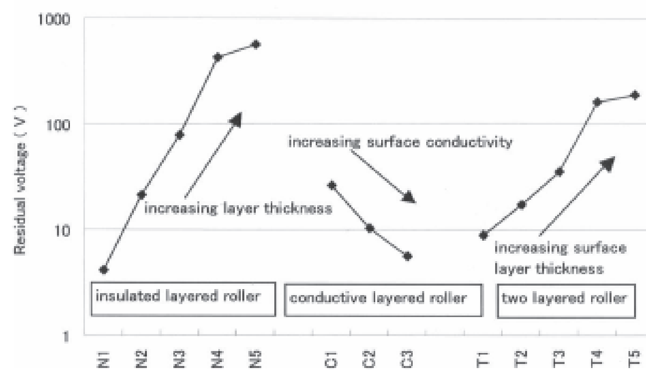

Figure 3. Results of residual voltage in each roller.

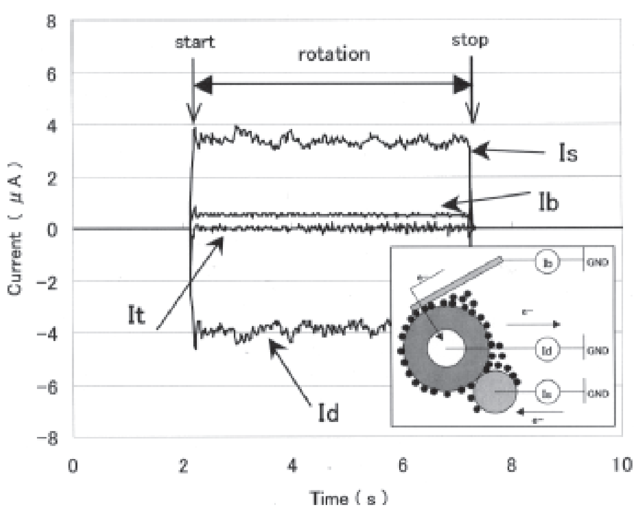

Figure 4. Currents through each part for roller F1.

shielded suction tube by a vacuum pump. The OPC drum was removed from the machine for the toner charge measurements. The power supply condition for each part was set as same as in the LBP machine. 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 the toner was removed. This also allowed the charge/area (q/a) to be calculated.

Measurements of Current at Each Part in Development Process

Three electrometers were connected between each development unit part (blade, development roller and toner supply roller) and the power supply for applying external bias voltage. The external bias voltages applied were the same as normally used in the LBP machine. 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.

Measurements of Imaging Density

As described above, a commercial LBP machine was used for printing images. For all the black solid images printed the imaging density (ID) was measured by a photo-densitometer (Macbeth RD918). The ID at five points both for the front and the back of the printing image were measured and the data averaged.

Experimental Results

Charge Relaxation—Residual Voltage of Development Roller

Examples of charge relaxation curves for the N3 roller (insulating layer roller, 20% resin content, zero CB content), the C2 roller (conductive layer roller, 20% resin content, 20% CB) and the T3 roller (two layer roller, 20% resin content, 20% CB + 20% resin content –zero CB) are shown in Fig. 2. The surface voltage decayed faster in the C2 roller than either of the other two rollers. The relaxation time of the development roller varies because of the nature of the highly resistive layer coated on the surface. The relaxation time of the T3 roller is in the middle of these three rollers. It is understood that surface charge relaxes much faster when a lower resistive layer is coated under the high resistive surface. In normal operation the roller rotates at 171 rpm in the development roller system and thus it takes 0.35 s for one rotation. We defined the value of the surface potential at 0.35 s in the relaxation curve as the "residual voltage" in this article. The results showing the residual voltage for all rollers are shown in Fig. 3.

Current Measurements

The currents at each section in the development process (Id: through the development roller, Ib: through the blade, Is: through supply roller, It: total current) were measured. The roller driving system was used for this measurement, and external bias voltages were applied using the same conditions as in the LBP machine. Figure 4 shows the results of the current measurements for the N1 roller. Electrons flow from GND to the blade or supply roller, and flow through the development roller to the GND. The current flows were observed in each part 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. Also no current was observed through each part when the roller did not rotate. This result shows that no current leakage occurred between each part whenever the external voltage is applied. Therefore, it can be concluded that the currents observed originate from the tribocharging of the toner and/or the toner development.

The average of each current for different rollers was calculated and the results are shown in Figs. 5(a), 5(b)

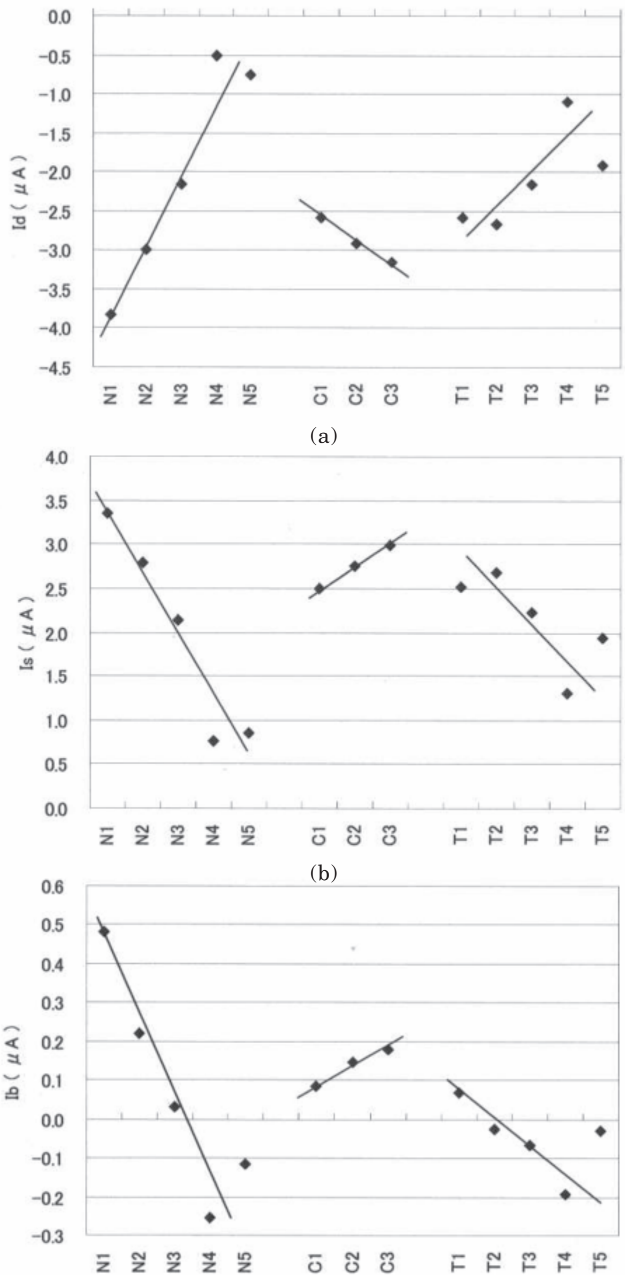

Figure 5. Current measurement results. (a) development roller (*Ib*); (b) supply roller (*Is*); and (c) blade (*Ib*).

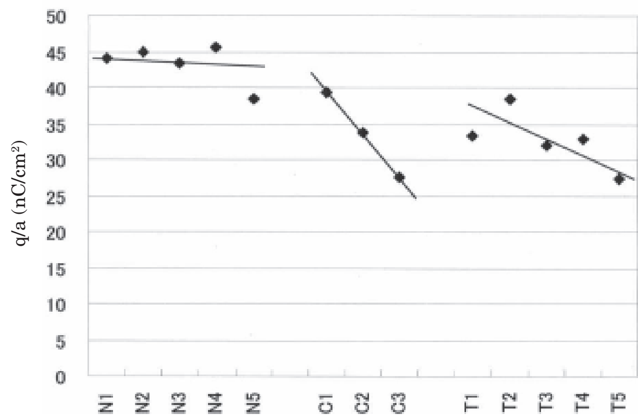

Figure 6. Toner charge (*q*/*a*) for each roller.

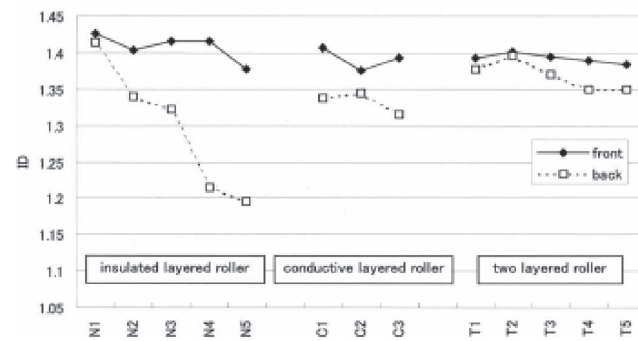

Figure 7. Image density at front and back point of the printed image.

and 5(c). As shown in Figs. 5(a) and 5(b), the currents through the development roller and the supply roller have a similar trend. The currents decrease in magnitude with an increase in thickness of the insulated layer (N1 to N5 rollers). The currents increase slightly with an increase in conductivity of the surface layer (C1 to C3 rollers). In the case of two layered roller (rollers T1 to T5), the current magnitudes decrease with increasing surface layer thickness similarly to the N1 to N5 rollers. In all cases the blade current is very small as shown in Fig. 5(c).

Toner Charging in the LBP System

The toner charging and mass transfer were measured at the same time as the current measurements. The toner charging characteristics for each roller are shown in Fig. 6. The toner charge to area ratio (q/a) decreased with an increase in surface conductivity, as can be seen most obviously in the case of the C1 to C3 rollers. The two layered rollers (T1 to T5) tend to show slightly lower q/a level than the single layered CB free rollers and decrease further with an increase in surface layer thickness. The toner mass transfer is related to the surface roughness of the development roller, but as shown in Fig. 6 the toner charging ability of single layered CB free rollers (rollers N1 to N5) is approximately constant. The surface roughness did not change greatly among rollers prepared in this study, thus the surface roughness of the development roller surface should not significantly affect the toner charging ability in this case. Also the toner charge is influenced by the voltage bias between the development roller and the supply roller. The highly resistive roller could produce a small bias voltage difference, thus reducing the toner charging due to the supply roller. As shown in Fig.6, however, the reduction is negligible for rollers N1–N5 and T1–T5, and of the order of 35% for rollers C1–C3. These results show that the bias voltage is not the main factor for toner charging in this system. We have studied this process in detail and showed that the toner charging is mainly affected by the blade–toner–roller interaction.[8]

Image Density of Black Printing

The results of the image density (ID) for each roller are shown in Fig. 7. The image density of the back point

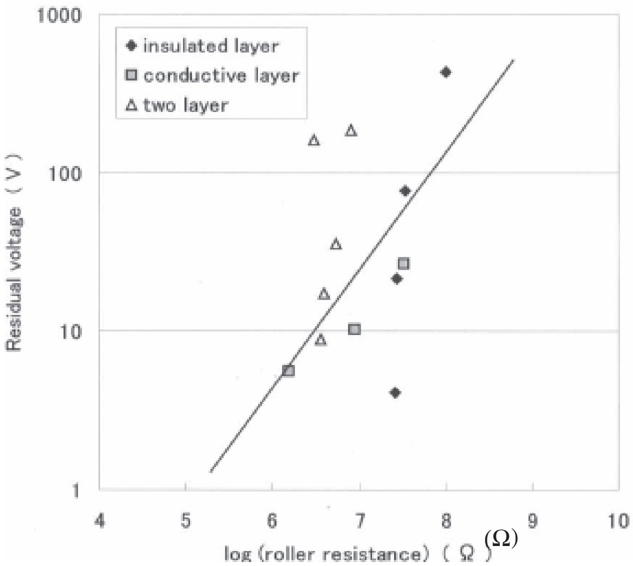

Figure 8. Relationship between roller resistance and residual voltage.

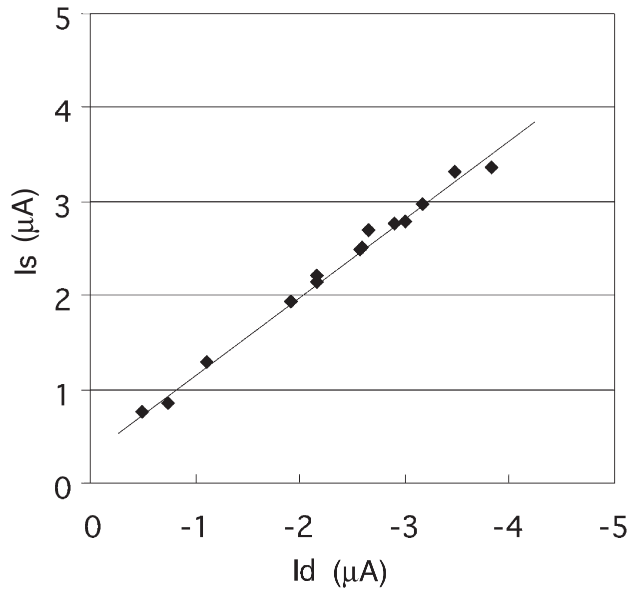

Figure 9. Relationship between development roller current (*Id*) and supply roller current (*Is*).

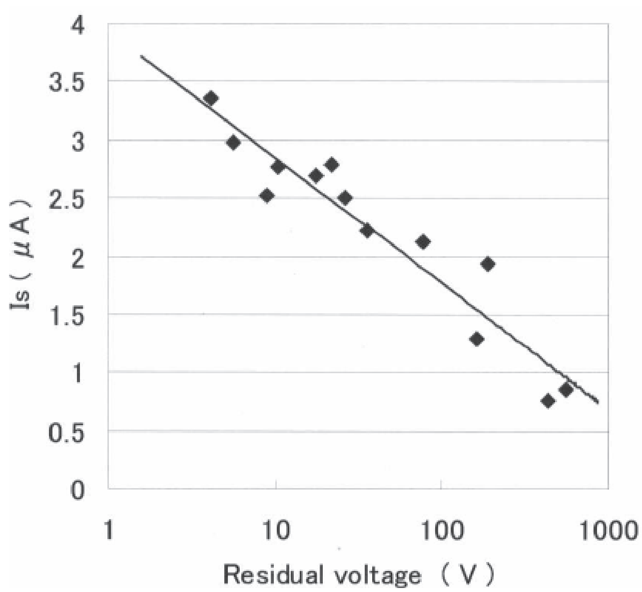

Figure 10. Relationship between residual voltage and supply roller current (*Is*).

decreases drastically with increasing the high resistivity surface layer thickness. (rollers N1 to N5) In the case of the conductive layered rollers (rollers C1 to C3), the back ID decreases slightly with an increase in surface conductivity. The two layered rollers (rollers T1 to T5) have the same tendency as observed in the highly resistive layered roller. However, the ID difference between front and back is much smaller than that with the high resistivity layered rollers.

Discussion

Relationship Between Current, Toner Charging, and Roller Features

Figure 8 shows the relationship between the roller resistance and residual voltage. In general the residual voltage increases with an increase in roller resistance. However the relationship between these two parameters is not clear. From the results of Figs. 3 and 8, the roller surface properties seem to be more important for determining the residual voltage than the roller bulk conductivity.

Figure 9 shows the relationship between the current through the development roller and the supply roller. There is a clear linear relationship between them. As shown in Fig. 5(c), the current through the blade is much smaller. These results suggest that the main negative current flows from the supply roller to the development roller. This current will be the main focus of this discussion.

The relationship between the supply or development roller current and roller resistance were not significant. These results suggest that the roller resistance is not a main factor for determining the current. The relationship between the supply roller current and the residual voltage is shown in Fig. 10. The correlation is very significant in this case.

There are no significant relationships between the toner charge to mass ratio, the toner mass per unit area on the development roller, the toner charge per unit area and the residual voltage. Similarly no relationship exists between these parameters and the current through the supply roller. From these results, it can be concluded that although the residual voltage of each roller strongly affects the current it has very little effect on the parameters specific to the development process.

Influences on Printing Images

The influence of the roller features, toner charge and mass on the development roller, and the roller current on the imaging density are now discussed. From the results of the image density measured at the front point (F–ID), back point (B–ID) and the difference between them (ID–Diff), correlation coefficients were calculated and tabulated in Table II. The correlation coefficients between F–ID and toner mass (*m/a*) and toner charge (*q/a*) are very large, which suggests that the higher toner mass provides higher toner mass development to the OPC. However no significant relationship is observed

TABLE II. Correlation Coefficients

	F-ID	B_ID	ID-Diff
Roller resistance	0.66	–0.36	0.50
Surface roughness	0.62	0.64	–0.51
Residual voltage	–0.20	*–0.85*	*0.82*
q/m	0.08	–0.35	0.37
m/a	*0.69*	–0.01	0.17
q/a	*0.71*	–0.22	0.39
Id	–0.25	*–0.79*	*0.75*
Is	0.22	*0.82*	*–0.78*

between B–ID and m/a or q/a. In the results of Table II, the residual voltage is the most significant parameter which affects the B–ID and ID–Diff. On the other hand, as shown in Fig. 10, the residual voltage and the current through the supply roller (Is) (or current through development roller (Id)) show a significant correlation. Thus the correlation coefficients between B–ID, ID–Diff and these currents are very large. From these results, the residual voltage of each roller can be considered to be the key parameter for discussing ID difference between front and back images.

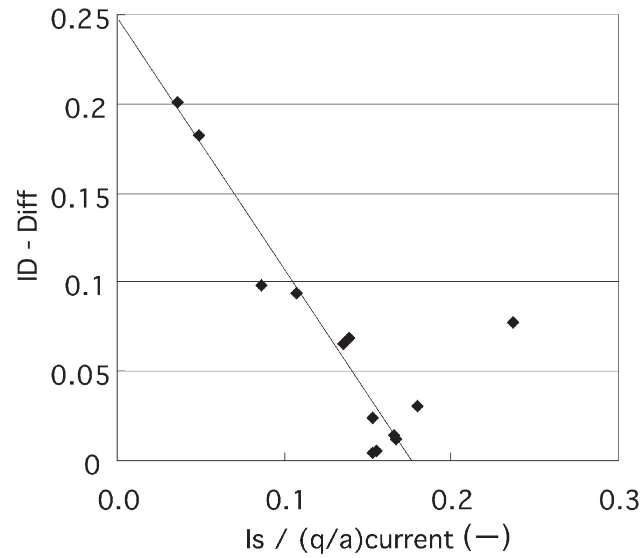

Figure 11. Relationship between current ratio (Is)/(q/a) and ID difference.

Discussion for the Toner Development Process

In normal operation the charged toner is removed from the development roller surface and new toner is attached on the roller surface by the supply roller. The current is determined by this process.[8,9] The toner charge (q/a) can be converted to current by calculating the development roller surface rotation speed (15.2 cm/s), roller diameter (2 cm) and roller length (30 cm). We define this calculated current as $(q/a)_{current}$ in this article. Thus the current ratio $[Is/(q/a)_{current}]$ is a measure of the ratio of the toner mass on the development roller to the toner mass removed and reset by the supply roller. A small $Is/(q/a)_{current}$ indicates that the toner cannot be removed by the sup2ply roller from development roller surface. The relationship between $Is/(q/a)_{current}$ and ID difference (ID–Diff) is shown in Fig. 11. The ID difference (ID–Diff) decreases with an increase in $Is/(q/a)_{current}$. The one exceptional point is from the C3 roller. This roller has a very high conductivity. It is suggested the leakage current between the supply roller to the development roller is very large, and in this case the supply roller current magnitude is shifted more than for the other rollers. In the case of small $Is/(q/a)_{current}$, the toner is not removed completely by the supply roller, and the some toner remains on the development roller surface. These toners should influence printing at the back point of the image, and the properties of these toners are different from those of the toners used for printing the front point image. It is concluded that this phenomenon causes image density difference (ID–Diff).

The relationship between $Is/(q/a)_{current}$ and residual voltage is shown in Fig. 12. This figure represents a very good relationship. The large residual voltage means that the charge is readily retained on the roller surface. Thus it is concluded that the residual voltage of the development roller affects image density difference (ID–Diff), and the mechanism of this difference is explained by the Is to q/a ratio.

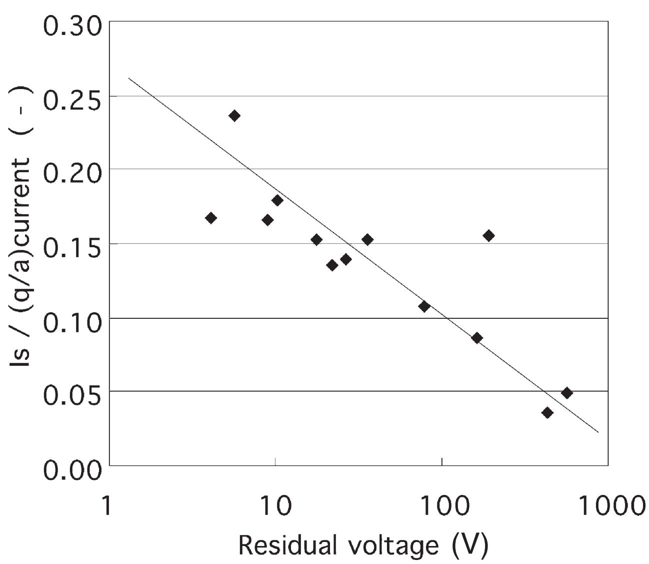

Figure 12. Relationship between residual voltage and current ratio $Is/(q/a)$ current.

From the results discussed above, we propose the following mechanism.

(1) Larger residual voltage means that charge will remain longer on the development roller surface.
(2) The roller, which has a large residual voltage, shows strong coulombic force between the toner and the roller surface causing large adhesion forces.
(3) The toner removal/supply efficiency for the supply roller becomes low for rollers with large residual voltage.
(4) The residual toner on the development roller surface is tribocharged again by the doctor blade, and it becomes more highly charged.
(5) The condition of toner charging on the development roller surface thus becomes different from the first rotation.
(6) ID difference between front and back occurs, and this phenomenon causes reduced uniformity of the printed image.

Conclusions

The mechanism of monocomponent non-magnetic toner charging and the mechanism of toner development in the electrophotographic system are discussed by using a current measurement technique. It was confirmed that the currents flow through each part, i.e., the development roller, blade, and supply roller, only during the roller rotation with toner attached to its surface. This current is strongly affected by the development roller surface properties. The "residual voltage" of the roller surface is a meaningful measure of the effective resistivity of roller, and this "residual voltage" affects the currents. It is proposed that the toner remove/supply efficiency by the supply roller can be estimated through these current measurements. Finally we proposed a mechanism for the non-uniformity of printed images. These considerations suggest that a development roller with two layers can have a sufficiently low bulk resistance and low residual voltage at the surface. The roller designed on this concept gives stable toner charging and produces high uniformity of images printed.

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